FEB 7 1983
834-C NS1.2:T22/20

(7)

ORIGINAL

COMPLETED
241

ANALYSES OF FIVE NATIONAL SCIENCE FOUNDATION EXPERIMENTS TO STIMULATE INCREASED TECHNOLOGICAL INNOVATION IN THE PRIVATE SECTOR

nsf

ANALYSES OF FIVE NATIONAL SCIENCE FOUNDATION EXPERIMENTS TO STIMULATE INCREASED TECHNOLOGICAL INNOVATION IN THE PRIVATE SECTOR

Edited by R. M. Colton

PREFACE

In 1972, the National Science Foundation established the Experimental Research and Development Incentives Program* with the objectives of experimenting with methods for

(1) stimulating the rate of adoption of the results of science and technology and

(2) increasing non-Federal investment in research and development.

In this vein, from 1972 to 1974, five major experiments were initiated that primarily focused on methods to stimulate increased private-sector investment in and utilization of research and development. By 1979 the experiments were by-in-large completed and separate analyses of each experiment were conducted and published.

This publication presents the results of all five of the analyses in a single volume as a reference document for academic, governmental, and industrial researchers and practitioners interested in models for stimulating technological innovation.

The five experiments arranged in their original order of implementation and as presented in this publication are:

- The National Science Foundation's Federal Laboratory Validation Assistance Experiment
- The National Science Foundation's University-Industry Cooperative Research Centers Experiment
- The National Science Foundation's Innovation Centers Experiment
- The National Science Foundation's Experiment on Federal Actions to Accelerate Utilization of Civilian Oriented R&D
- The National Science Foundation's Medical Instrumentation Experiment.

R. M. Colton
May 1982

---

*Programs are now under cognizance of Industrial Science and Technological Innovation Division

TABLE OF CONTENTS

Section I.
An Analysis of the National Science Foundation's Federal Laboratory Validation Assistance Program

Section II.
An Analysis of the National Science Foundation's University-Industry Cooperative Research Centers Experiment

Section III.
An Analysis of the National Science Foundation's Innovation Centers Experiment

Section IV.
An Analysis of the National Science Foundation's Experiment on Federal Actions to Accelerate Utilization of Civilian Oriented R&D

Section V.
An Analysis of the National Science Foundation's Medical Instrumentation Experiment

SECTION I.

An Analysis of the National Science Foundation's Federal Laboratory Validation Assistance Program

I

This description of the Federal Laboratory Validation Assistance Experiment was prepared by the Denver Research Institute for the National Science Foundation; Louis F. Cicchinelli is the author. The content is based on reports and other material provided by the former NSF Program Manager, Evan Anderson, and on interviews with persons submitting proposals to the Federal Laboratory Validation project or persons knowledgeable about the activities of the projects discussed in this report. In addition, R.M. Colton, currently the NSF Program Manager, has reviewed this report and concurs as to the authenticity of the data. Any opinions, findings, and conclusions or recommendations are those of the author and do not necessarily reflect the views of the National Science Foundation or of the participating federal laboratories.

Center for Social Research and Development
Denver Research Institute
University of Denver
Denver, Colorado 80208

II

An Analysis of the NATIONAL SCIENCE FOUNDATION'S FEDERAL LABORATORY VALIDATION ASSISTANCE EXPERIMENT

an effort to stimulate
the rate of technological
innovation in the public
and private sectors

PREFACE

The Federal Laboratory Validation Assistance Experiment (FLVAE) is one of several experiments initiated by the National Science Foundatin to identify, test, and evaluate incentive strategies and institutional arrangements for stimulating technological innovation in both the private and public sectors.

Specifically, FLVAE is an attempt to assess the value of federal assistance in product/process performance validation. Performance validation is a key step in the progress of an innovation from concept to the market. This assessment is based on twelve case studies, four of which received federal funding and eight of which were not funded.

The information presented in this document summarizes the experiment and related findings. Statistical evidence is not sufficient to establish specific roles for the federal government in performance validation of new products. However, the findings described herein can serve as a basis for development of federal policy in this area of national need.

R. M. Colton
January 1978

SUMMARY

The Federal Laboratory Validation Assistance Experiment, sponsored by the National Science Foundation, was designed to determine the effect(s) of supplying federal funding for performance validation of new products or processes on the success of such technological innovations. Under the auspices of the experiment financial assistance was provided to four organizations for the validation of their new products or processes. In addition to these funded projects, over forty requests for assistance were received but were not funded. In an effort to assess the impact of this experiment and to isolate those findings which might aid decision-makers in implementing similar assistance programs in the future, a case history analysis of twelve projects--four funded and eight non-funded--was conducted.* This report has been prepared to present the more salient aspects of that analysis.

The analysis addressed five definable questions:

- Who should receive validation assistance?
- At which stages in the innovation process should assistance be provided?
- How should projects be selected for assistance?
- Where should the testing be conducted?
- How should the test results be used?

In general the provision of validation testing for new products/processes seems to be effective in increasing the rate of technological innovation, particularly among private innovators. It appears, however, that individuals and companies require assistance at quite different stages in the innovation process.** That is, private innovators often need external assistance in concept validation and prototype construction, whereas many companies are able to support these development stages using in-house resources. Further there is considerable agreement among those interviewed that federal assistance should be made available only

---

*Cicchinelli, L. F. and Burton, L. An Analysis of the Federal Laboratory Validation Concept. Denver Research Institute, Report No. R 77-01, October 1977.

**Robbins, M. D., Burke, C. A., and Milliken, G. J. Federal Incentives for Innovation: Part II--The Innovation Process in the Private and Public Sectors. Denver Research Institute, November 1973.

if the innovation is in "the public interest" and only if it can be determined that it will advance the "state-of-the-art." While federal laboratories have provided more than adequate test facilities, thought also should be given to involving independent laboratories in a validation program. Finally, the test plan and reporting procedures require special attention. The results of tests which validate (or invalidate) claimed performance should be reported separately from test results which are more exploratory in nature. These latter tests are often designed to investigate unanticipated product/process capabilities and limitations and are usually only tangentially related to the intended purpose of an innovation.

TABLE OF CONTENTS

Summary
v

Introduction
1

The Problem
4

The Experiment
6

Summary of Projects Reviewed
9

General Findings and Conclusions
23

INTRODUCTION

The National Science Foundation's Industrial Programs Office (NSF/IP) is designed to stimulate increased non-federal investment in research and development and to accelerate the commercial application of research results. To reach these goals, NSF supports work to help identify, test, and evaluate the incentives that can be used to encourage R&D investment and the barriers that might impede it. The Federal Laboratory Validation Experiment was specifically designed to determine the effect(s) of supplying performance validation for new products or processes on the rate of technological innovation.

It was originally proposed to assess the outcome of the experiment by comparing the status of innovations for which NSF provided validation assistance funding with those innovations which were rejected for funding on the basis of predetermined NSF and laboratory selection criteria. However, an early shift in program emphasis, which changed participant eligibility from the private sector to the public sector, resulted in a marked drop in requests for validation testing assistance. It was not possible, therefore, to assess completely the impact of the program according to the originally proposed experimental design because the number of participants was considerably smaller than anticipated. A case history analysis was conducted as an alternative approach to assessing the outcome of the experiment.*

The objective of the analysis was to evaluate the use of federal funding for supporting federal laboratory validation testing for new technological products/processes. Follow-up information obtained from companies participating in the experiment and companies/individuals requesting, but not receiving assistance, was expected to provide insight into the need for validation assistance and the best techniques for delivering such services.

NSF/IP funded four requests for federal validation assistance, under the guidelines of the Federal Laboratory Validation Assistance Experiment. Approximately forty other companies/individuals requested validation assistance in response to the original NSF program announcement in 1972, but were not funded because they did not meet the prescribed criteria. Eight of these nonfunded proposals were reviewed as part of this case history analysis. These eight proposals were selected on the basis of current accessibility of key persons and the completeness of available documentation. They are representative of the type of requests received by NSF. In total, then, twelve projects were reviewed and they are briefly described in Table 1. All information presented in the "Findings and Conclusions" section of this report are based on documentation supplied by NSF officials and interviews with selected key personnel involved in each of the twelve projects.

---

*Cicchinelli, L. F. and Burton, L. An Analysis of the Federal Laboratory Validation Concept. Denver Research Institute Report No. R 77-01, October 1977--available upon request from the National Science Foundation.

Table 1
The Twelve Proposed Innovations Reviewed

Ultrasonic Waste Water and Sewage Treatment Processor

an ultrasonic system for increasing the dissolved oxygen level and thus the bacterial activity in sewage

Ozone Water Purifier

the miniaturization of large municipal ozone water treatment plants for home use

Evapotranspiration System

a system that combines the effects of evaporation and transpiration to treat home wastes to be used as an alternative to conventional septic tanks

Transette Personal Transit System

a personal rapid transit system concept based on unpowered cars operating on a series of belted guideways

TapTone Can Inspection System

a system for inspecting cans for defects by analyzing variations in pressure or vacuum through the use of an electromagnetic pulse

Textile Inspection Device

an automatic textile inspection device which uses transmitted light to locate defects in cloth

Aerocrane

a vehicle for moving heavy payloads that combines the aerostatic lift of balloons with the aerodynamic thrust for lift and translation of a helicopter

Neurotone

a device to reduce anxiety and depression through the use of cerebral electro-stimulation

Jifskid Toilet

an elaboration of the dual flushing system which utilizes hydraulic action to flush rather than a syphoning action

"See-All" Mirror

a device consisting of a series of alternate deviating and non-deviating stripes of transparent, flexible, optical grade polyvinyl chloride for use as automobile mirrors

Coal Desulphurization Process

a process for removing sulphur from coal by introducing iron powder during the grinding phase and using a centrifuge to remove all coal impurities

La Force Car Engine

an engine which burns gasoline more efficiently primarily by recycling fuel through a heating and cooling system to increase volatility

THE PROBLEM

This experiment assumes that proving the validity of claimed performance of a product or process is an essential part of the development and commercialization of new technology. The process for obtaining such proof is called validation testing and is necessary regardless of the specific inventor (e.g., large corporations, small companies, or individuals). However, small companies and individuals typically must seek outside sources of investment capital to proceed with the development of their innovations. In general, at points where a venture capitalist assumes the risk involved in a new technology, some form of validation testing is required.

One example occurs at the point where a concept has been developed and tested by analytical methods. If concept verification is not available, a venture capitalist may consider the technological risk too high for investment. Thus, technical and prototype development is blocked at this stage. A second point at which a transfer of risk may take place is in the marketing of an innovation. When a new technology reaches the marketing stage, performance validation is required to persuade investors to provide the needed capital and buyers to "gamble" on the new product. A common example of this situation occurs in state and local governments when agencies are introduced to new technologies which may prove useful in solving existing important problems. Without proper performance verification, however, adoption is unlikely because of the apparent high risk that is inherent in such a decision.

Clearly then, a major barrier to the development of innovations in the private sector is the difficulty of obtaining venture capital, particularly without prior validation. The Federal Laboratory Validation Experiment was designed to address this issue by offering support for performance validation testing in federal or accredited private laboratories to state and local governments on a cost-sharing basis. It was assumed that performance validation of new technology would reduce, or at least clarify, the potential risk of investment in the development and marketing of new products and processes.

A second, more subtle barrier to the development of innovations in the private sector involves patent rights. In seeking sources of venture capital, the inventor runs the risk of losing all or part of the patent rights to his invention. This is especially true for private inventors and small companies who have an innovation that is still in the concept stage and not yet marketable. This potential problem was directly addressed by clearly reserving the patent rights for the inventor in a cooperative validation agreement among NSF, the validating laboratory, and the inventor.

A barrier to the development of innovations in both the private and public sectors is the problem of locating appropriate test facilities. Validation testing requires facilities and technical staff capable of designing and carrying out detailed validation protocols. The federal laboratory system offers a broad range of appropriate facilities.

A fourth barrier to the adoption of new technology in the public sector is the lack of the technological capability on the part of the buyer that is necessary to understand and evaluate the new technology.

Although both concept and performance validations are critical to the development and utilization of new technology, this experiment provided only performance validation testing for technological products or processes having potential applications in the public sector. Specifically, the experiment was oriented to determine whether a lack of verification capability is, in fact, a significant barrier to the technological innovation process in the public sector. The decision to focus on the public sector was made, in part, to circumvent some of the legal difficulties associated with providing public funds for private ventures, and to simplify the selection process--since all proposals could not be funded. Providing validation testing for only those innovations which could be utilized by state or local governments was expected to insure that the new technologies are "in the public interest." Nevertheless, the original objective of the experiment was retained in that innovations emerging from the private sector were eligible for validation testing if they had public sector support.

In short, then, this experiment was designed to investigate the effectiveness of providing *performance* validation for new technology, having public sector support, in overcoming some of the barriers to an efficient innovation process.

THE EXPERIMENT

The Federal Laboratory Validation Experiment was designed to determine the effect(s) of supplying performance validation for new products or processes on the rate of technological innovation. The incentive tested in the experiment involved the use of federal and accredited private laboratories for validating new technological products or processes. The test laboratory was selected on the basis of mission relevancy, and the availability of test equipment and manpower at the laboratory.

Companies/individuals requesting validation assistance had to demonstrate that other potential validation resources had been explored, and that the innovation to be tested had a strong potential for advancing the "state-of-the-art" and was in the public interest. The selected test facility assessed the technical merit of the new development and determined whether it could conduct the required performance validation. The laboratory performed neither developmental work with regard to the project nor interpreted test results, except when specifically requested to do so by the public agency.

All requests for federal laboratory validation assistance were evaluated by the same criteria (Table 2). The individual or organization requesting assistance contacted the National Science Foundation and submitted a preliminary proposal. NSF identified a laboratory that was qualified to evaluate the proposal and to conduct subsequent tests. The requester then interacted with the selected laboratory directly. If the proposal met the program requirements for funding, the proposer and the laboratory negotiated the test program, which included test parameters, tolerances, methods, schedules, costs, and so on. At this point in the process, NSF negotiated a cost-sharing agreement with the proposer which was based, in part, on potential profit and degree of public interest in the new innovation. In general, the validation testing award was made directly to the laboratory prior to the commencement of testing.

NSF usually was involved in a tri-party contractual agreement for each project accepted. One portion of the agreement was with the initiator of the project while the other was with the management of the laboratory selected to perform the validation testing. The agreement between the initiator and NSF included a description of the work plan, explicitly describing the validation testing program to be used. The cost-sharing arrangements, timetable, reporting procedures,

Table 2
Proposal Selection Criteria

NSF evaluated all proposals on the following criteria:

- The product or idea must attract a strong or potentially strong public interest.
- The project will not be subject to subsequent tests for regulatory purposes.
- The initiator should have exhausted all avenues available to him for similar aid.

If these conditions were met, the laboratory evaluated the proposal on the following criteria:

- There must exist a strong potential for advancing the state-of-the-art.
- There must exist a physical article to test.
- If testing begins, it must not interfere with the cooperating laboratory's ability to fulfill its existing obligations.
- The project should be compatible with the technical expertise and facility capability existing in the laboratory.
- The laboratory shall concur in developing a detailed test plan.

terms of delivery of the items to be tested, and a full technical description of the innovation to be tested were also included. This agreement clearly stated that the government would not take title to any patent or impinge in any way on the proprietary rights of the initiator. Further, U.S. Code Title 18, Section 1905, prohibiting the willful disclosure of proprietary data by federal employees applied. Finally, the agreement stipulated that the results of the final report could not be cited out of context. They could be used only by transmittal or citation of the full report.

The elements of the Interagency Agreement between the agency performing the testing and NSF included a statement of the scope of the work, time schedule, and reporting procedures, as well as the cost and method of reimbursement agreements. A liability agreement was included when necessary and again, the proprietary rights of the innovator were safeguarded.

SUMMARY OF PROJECTS REVIEWED

The section provides a brief description of the twelve projects reviewed. Tables 3 and 4 provide a summary of the current status of each project.

Ultrasonic Waste Water and Sewage Treatment Processor

Ecquacon Corporation of Matawan, New Jersey, was incorporated in June, 1972, and has one salaried officer (the president) and two other directors. The firm was formed for the purpose of developing and promoting a proprietary system for the treatment of waste water and sewage. Ecquacon has developed a process which uses ultrasonics to stimulate bacterial activity in sewage by increasing the amount of dissolved oxygen in the water.

The Environmental Protection Agency's National Environmental Research Center (EPA/NERC) was contacted by NSF as the potential validation facility. As a result of the favorable review by EPA/NERC, the Ecquacon proposal was approved, and the Edison Water Quality Research Laboratory located in Edison, New Jersey, was selected as the test facility.

At about the same time that the firm contacted the National Science Foundation, negotiations were underway to license the sewage treatment system to another firm, Parker-Hannifin. Effectively, Parker-Hannifin gained use of Ecquacon's patent; if the tests were successful, they would produce and market the system and pay royalties to Ecquacon. In June, 1975, Liquid Sonics Systems, in Florida, was awarded the sublicense and was charged with the manufacture, marketing, and continued engineering and development of Ecquacon's Waste Control System.

It is difficult to show that NSF's provision of validation testing assistance was responsible for the agreement between Ecquacon and Parker-Hannifin, though much-needed capital was forthcoming in the form of support from a large conglomerate. Positive scientific support of the system was not a result of the various tests at EPA/NERC, though it had been the intention of the Ecquacon founders to use the certified data to attract the capital the firm needed.

Ozone Water Purifier

Alron Industries, Inc., in Rochester, New York, was founded in March, 1971, and has less than ten employees. Its main

BEST DOCUMENT AVAILABLE

Table 3
Nonfunded Projects Reviewed

Innovation	Innovating Company/ Individual	Reason Funding Was Not Provided	Was Additional R&D Conducted Without NSF?	Is the Innovation On the Market?
Taptone Can Inspection Device	Benthos, Inc.-employs about 90 persons.	No formal proposal was submitted. The company had already marketed the first generation.	Yes	Yes
Textile Inspection Device	American Electronics Laboratories-employs about 1200 persons.	Proposal was from the private sector solely.	No	No
Aerocrane	All American Industries, Inc.-employs about 1175 persons.	Proposal was from the private sector solely.	Yes	No, but prototype testing continues.
Neurotone	Neuro System, Inc.-employs less than 10 persons.	Proposal was from the private sector solely.	Yes	Yes
Jifskid Toilet	Mr. J.R. Wilhelm-an individual inventor.	No prototype was available for testing.	No	No
Seeall Mirror	Mr. N. Berman-an individual inventor.	No prototype was available for testing.	No	No
Coal Desulphurization Process	Dr. J. Winkler-an individual inventor.	No prototype was available for testing.	No	No
LaForce Car Engine	Mr. E. LaForce-an individual inventor.	No formal proposal was submitted.	No	No, although testing by other agencies has been completed.

Table 4
Funded Projects Reviewed

Innovation	Innovating Firm	Validation Testing Status	Was Additional R&D Conducted?	Is the Innovation On the Market?
Ultrasonic waste water treatment system	Ecquacon Corp.- employs less than 5 persons	Completed	Yes	Yes
Ozone water purification system	Alron Industries, Inc.- employs les than 10 persons	Completed	Yes	Yes
Evapotranspiration sewage system	Virginia Polytechnic Institute	In progress	--	No, although variations of the process have been marketed
Transette, a personal transit system	Transette Corp. & Georgia Institute of Technology	NSF support has ended, testing is continuing at a low level	--	No, potential clients awaiting test results

// BEST DOCUMENT AVAILABLE

products ae a line of water softeners and an ozone generator, the central component of a water purification system which Alron manufactures for use in private homes and small businesses. The new technology which Alron has introduced in the United States is an automated, miniaturized version of large municipal ozone water treatment plants for use in private homes and other small installations.

In January, 1973, Dr. Burris, president of Alron, proposed a test of the Alron Ozone water purifier, and the Environmental Protection Agency's National Environmental Research Center (EPA/NERC) was selected by NSF as the test facility.

Dr. Burris viewed the main value of the testing program to be the technical data obtained which would be useful for further technological development of the water purification system. He also noted a lack of communication between the testing agency and the innovator, and suggested that if he had been able to send an employee to the test site, some of the problems encountered during the testing period might have been avoided. Dr. Burris received permission to abstract a portion of the validation testing report, but stated that the tone of the report (its complexity, use of scientific jargon, etc.) prevented its use in a marketing effort. Dr. Burris recommended that the positive test reports relating to the claims of the product be released independently of the full report.

Evapotranspiration System

Dr. Harry J. Pence of the Virginia State Technical Services, Virginia Polytechnic Institute and State University, submitted a proposal to NSF for testing a disposal system for individual household wastes. Since the evapotranspiration process cannot be patented and standard septic tanks or aerobic equipment is used in conjunction with the evapotranspiration bed, no specific private inventor or firm was involved in the proposal. Evapotranspiration systems function through the combined effects of evaporation of water from the soil and the normal transpiration of liquids through relatively high water-using plants. The test system as proposed consisted of a treatment tank, where solids and grease are removed from the household waste water, and an evapotranspiration bed. (Figure 1.)

On 12 December 1974, Dr. Pence submitted a preliminary proposal to NSF for the evaluation of an evapotranspiration system. It was proposed that a system be tested in problem areas in each of seven participating states. The seven states were Virginia, Maryland, Tennessee, West Virginia,

BEST DOCUMENT AVAILABLE

Figure 1. Evapotranspiration Bed

North Carolina, South Carolina, and Delaware. The formal proposal, submitted in early 1975, was reviewed by a panel of experts, including officials at the Environmental Protection Agency, the University of Wisconsin, and the General Electric Corporation. The State Technical Services branch at VPI&SU was awarded $100,000 for a twenty-four-month test.

Specifically, the VPI&SU office had administrative responsibility for the project while the Departments of Health (or an equivalent office) of the participating states would suppy field personnel to collect and analyze the obtained data. The states' share of the project cost totalled $69,000. A joint resolution was signed by the participating states with VPI&SU, providing for the collection of the data at the test sites under varying conditions of rainfall, wind, temperature, and humidity. A homeowner's agreement was also designed to specify the responsibilities of the homeowners at each of the sites.

It should be noted that this project was the only one in this experiment which did not directly utilize federal laboratories for the validation testing of new technology. The individual states participating in the testing program were charged with the collection and analysis of data in state laboratories. In an interview, Dr. Pence suggested that the data collection efforts might have been more efficient if he had sufficient funds to employ on-site data collectors.

Testing at the Virginia site was completed. The other sites are continuing to operate and data collection is expected to be completed within a year. Dr. Pence pointed out that if funds were available, it would be desirable to continue testing at all sites for another year. Although some preliminary results appear promising, additional tests would be helpful in determining the feasibility of the system under a wider range of environmental conditions.

The Transette Personal Transit System

Transette, Inc. was established in Marietta, Georgia, in 1972 to develop and promote the Transette system invented by Dr. J.F. Sutton, president of the company. Transette, a personal rapid transit system, is based on a concept of passive (unpowered) cars carrying four to six persons each, moving along a series of belted guideways.* A main goal of the system design is to minimize costs through extreme simplification of the cars, whose control mechanisms include only a basic clutch and brake. (* Figure 2.)

BEST DOCUMENT AVAILABLE

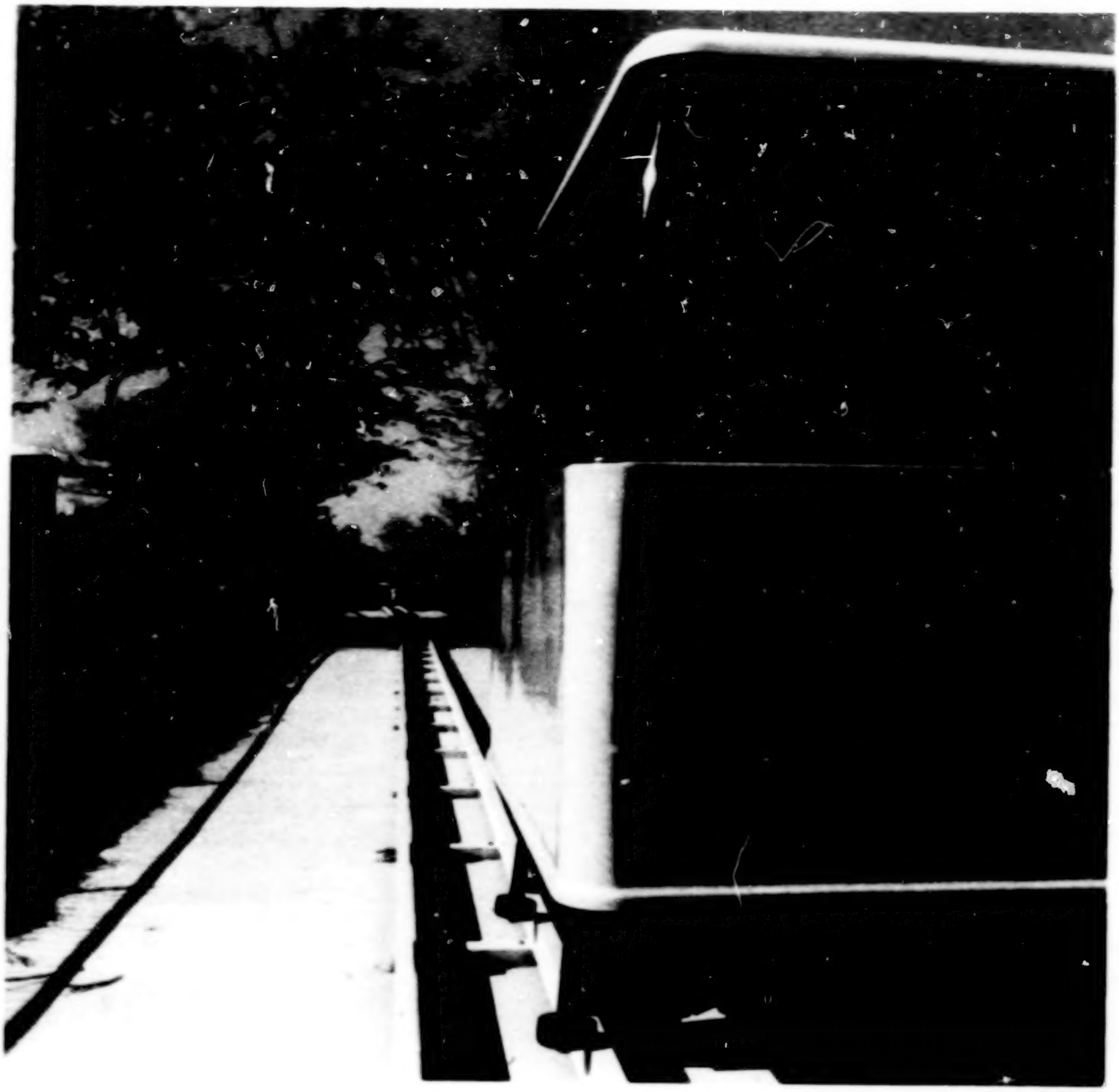


Figure 2. Transette Rapid Transit System

In May, 1974, a proposal for the concept and performance validation of the Transette System was submitted by the Engineering Experimental Station at Georgia Institute of Technology (GIT). The Institute was interested in the Transette System as an alternative to bus service presently offered on campus. In June, 1974, the GIT proposal was reviewed by NSF and Department of Transportation (DOT) personnel, and was judged to satisfy all the criteria for acceptance under the Federal Laboratory Validation Experiment.

Work proceeded well, both in the installation of the system at GIT and in the fabrication of the Transette cars. The cars were received from the manufacturer, wiring of the computer was completed by mid-July, 1975, and the test bed was completed. Despite these advances in project development, numerous delays have occurred in scheduling the official tests by TSC. Delays have resulted from bad weather, equipment problems, other on-campus construction, design changes, route relocation, and an internal reorganization of TSC. The proposed TSC tests were never completed, and NSF funding was officially terminated during 1977. GIT has submitted a proposal to the Urban Mass Transit Authority for the funding necessary to continue testing. Recently, limited private investment (Transette stock) has resulted from the improved system design which has emerged over the past few years, due in part to NSF involvement. Total new investments in R&D has nearly quadrupled the original NSF grant.

An NSF project official noted that one important fact learned from his experience with the project has been that it is extremely difficult for an inventor to start and maintain a new business, especially when the new business requires large amounts of capital. Federal participation in the form of validation testing has been important in influencing the decisions of venture capitalists to invest in the young company. It has also become clear that the success of such a project is to a large extent determined by the inventor himself. His perseverence and patience in overcoming obstacles and solving problems of all types is of utmost importance.

TapTone Can Inspection Systems

Benthos, Inc., founded in 1962 in Massachusetts, is a firm specializing in oceanographic equipment. The firm has gradually expanded its market to the international level, and now includes the offshore oil industry and the U.S. government. In 1972-73 the firm initiated a program to expand its operations into the area of nondestructive inspection devices for canneries. Benthos, Inc., developed a technique for inspecting cans which replaced the human element in judging the quality of a can, and which is capable of inspecting cans after they are packed and sealed in cartons.

The TapTone systems analyze variations of pressure or vacuum inside containers with metal tops by using an electromagnetic pulse which bounces off the top of the containers. The returned pulse is analyzed by an electronic discriminator which detects differences in the conditions inside the container by measuring the tone of the "ping" which returns to the discriminators.

On 2 March 1973, NSF requested a formal proposal from Mr. Raymond, president of Benthos. However, during a telepone conversation between Mr. Raymond and Mr. E. Anderson of NSF on 24 March, it was mutually concluded that the firm was too far along in the development of its product to really be able to profit from a test. Mr. Raymond decided not to submit a proposal at that time, but pointed out that unique problems arise when a firm tries to enter a field in which it has no experience. Marketing becomes a major concern since the company is entering new territory and must be particularly imaginative in order to successfully enter a field. He mentioned the specific problems of locating the correct magazines and journals in which to advertise and finding the appropriate sales representatives. He also noted that a firm should consult a marketing expert for advice, and should not try to break into a new field without such assistance.

In general, Mr. Raymond supports government assistance in product development only if the government activities do not interfere with or compete with the firm. He feels the government's stamp of approval in the form of product validation would assist firms trying to market a new product. However, the stage in R&D during which the government becomes involved should depend on the size of the company and its resources. Mr. Raymond noted, that while Benthos, Inc., generates enough profits to finance its R&D, federal validation would still be helpful.

Textile Inspection Device

American Electronic Laboratories (AEL), a technology-oriented firm established in 1950, owns four subsidiaries and maintains a controlling interest in two affiliates in Israel. Company headquarters are located in Colmar, Pennsylvania. In May, 1974, the company had 6,045 stockholders and employed over

1,200 personnel. The company and its subsidiaries manufacture a variety of products including: specialized communications systems; microwave components; transmitters; medical electronic instruments; automatic chemical dispensing equipment; and solid state materials and equipment. The firm's primary customer is the U.S. military which contracts with AEL for electronics and communications equipment.

The Industrial Products Division of AEL proposed an automatic textile inspection device to replace the normal manual inspection of flatgoods at the manufacturer. The proposed technique involved the coupling of an electronic scanner, and inspection frame, and a control console with power supplies and electronic logic. Basically, the amount of light transmitted through a piece of cloth passing over the frame would be "read" by a modified TV camera, and signals from the camera would be transmitted to a complete electronic system.

In May, 1973, after a number of positive reviews of the proposal, NSF and AEL officials met in Pennsylvania to discuss final negotiations. On 21 May 1973, NSF approved the project, and a contract between NSF, Natick, and AEL was drafted. On 20 June, focus of the Federal Laboratory Validation Experiment was altered to include only those innovations emerging from the public sector, and the project was not funded.

Mr. Riebman, of AEL, favors government support of such innovations. He did not suggest that the U.S. government become involved in product development in general, but that such assistance is needed in particular cases. These cases are those where certain pieces of equipment would be of major benefit to the user, but for which R&D costs are prohibitive to the manufacturer. The proper stage in development for government involvement is, according to Mr. Riebman, during idea formulation, since the risk is greatest and companies often are forced to make conservative decisions regarding R&D. Mr. Riebman also suggested that one government criterion for investment in private R&D should be the effects of the investment on the nation's import/export balance. He pointed out that these considerations were important in his project's development--one goal was to make U.S. textile mills more competitive internationally.

Aerocrane

All American Industries, Inc., (AAI) was originally incorporated in Delaware in 1952 as the All American Engineering Company. In 1970, the company changed its name to All

American Industries and International Controls Corporation is the major stockholder (81%).

AAI's product line includes: missile and rocket components; energy absorption devices for use with aircraft; airport safety devices; and power transmission towers.

The Aerocrane, developed by Mr. Crimmins and Mr. Doolittle at All American Industries combines the aerostatic lift capabilities of a balloon with the aerodynamic thrust for lift and translation of a helicopter. The vehicle consists of a helium-filled balloon to which four aircraft-type wings are fitted. Each wing carries a single aircraft engine, and the balloon and wings together rotate at approximately ten rounds per minute. Suspended from the main structure is a pilot and control cabin, which is attached by a swivel joint allowing it orientation to the direction of travel of the aircraft. The wings are adjustable to provide for vertical and horizontal directional and rate control; during unloaded conditions, the wings work against the balloon lift force to prevent the vehicle from rising rapidly.

A proposal from AAI requesting assistance in building a prototype was received at NSF on 25 June 1973. There was no prototype available for testing, but the United States Navy was, according to Mr. Crimmins, ready to conduct the tests. Further, a Forest Service evaluation was being conducted by the Aerospace Corp. at the time, and AAI was prepared to cost-share in the development of the project.

On 23 July 1973 the National Science Foundation informed Crimmins of the change in policy involving the Federal Laboratory Validation Experiment, and that NSF could consider only innovations emerging from the public sector. Mr. Crimmins mentioned that he was in contact with the city of Los Angeles concerning use of the Aerocrane for fire fighting, and asked if Los Angeles requested assistance, would he then qualify for assistance. NSF made no commitments, and there were apparently no further interactions between AAI and NSF.

Arthur Crimmins has moved to Canada and heads Aerocranes of Canada, Ltd., in Montreal. The Montreal company is supported by a private group and has obtained a grant from the Canadian government's Program for the Advancement of Industrial Technology (PAIT) for prototype development. The Canadian firm owns patents for the Aerocrane in Australia, Brazil, and Canada.

Mr. Crimmins believes that the Federal Laboratory Validation Experiment's major deficiency was its evaluation procedure for accepting proposals. He suggested that evaluation criteria should include benefits of the proposed innovation to the country and the world, potential marketability, and feasibility. He was also critical of what he calls an "anti-business" attitude on the part of the U.S. government, and does not believe that a program like the NSF experiment is possible. Instead, the National Science Foundation should focus its efforts on overcoming the "adversary" relationship between U.S. business and government. He compared the U.S. attitude with that of Canada, where he found a "strong, positive influence on innovation in Canada through the Program for the Advancement of Industrial Technology (PAIT) and other grant/loan programs designed to attract new technology and jobs to Canada." He concluded that the anti-business attitude of the U.S. government cannot be changed in any substantial way.

Neurotone

Mr. Gilmer, president of Neuro Systems, Inc., and his associates, founded the company in 1970 after purchasing the patent and all other rights to the Neurotone device from Varo, Inc. Mr. Gilmer had been head of corporate development at Varo, where had worked on sleep therapy for about three years.

The product called "Neurotone" employs the techniques of "cerebral electro-stimulation" (CES) therapy, which has been practiced in the Soviet Union since 1947. A series of applications of low intensity electric pulses are applied to the nervous system through the cranium on chronically anxious persons. It should be noted that the so-called "electrosleep" therapy provided by the Neurotone is not related to either sleep therapy or electrochock therapy currently in use. In fact, "electrosleep" is a misnomer; the technique does not induce sleep directly, but reduces the parameters of anxiety and depression associated with certain diseases which themselves prevent a patient from sleeping.

In May 1973, after considerable review, NSF approved the proposal for funding. However, by June a policy change, which altered the experiment's objectives, had been announced, and Mr. Gilmer was informed on 20 June 1973 that his project would not be funded.

Since 1973, Neuro Systems has diversified its product line but Neurotone has remained the company's main item. There are currently 800 users of the device throughout the United States, and a prescription item has been developed for home use. A new U.S. patent is pending which will cover the refinements and new versions of the Neurotone; the company now owns a patent in Britain and patents are pending in Japan and West Germany.

Mr. Gilmer supported the concept of federal laboratory validation assistance for new inventions and processes, stating that it was a good use of government facilities and staff. However, he cautioned that the government must realize that a private businessman in a free enterprise system needs some kind of economic motive to develop a product. This economic motive is not present in the university or public sector. He also pointed out that NSF is in a good position to take over the leadership in the area of providing incentives to technological innovation, since the agency is not mission oriented. Therefore, it is not a threat to the established domains of other government agencies.

Jifskid Toilet

Mr. J.R. Wilhelm applied for assistance from the National Science Foundation under the Federal Laboratory Validation Experiment for a water-saving toilet called "Jifskid." Mr. Wilhelm's innovation involves an elaboration of the dual flushing systems which are already protected by patent. His particular contribution is the installation of a by-pass valve in the back of the trap wall. Instead of the usual siphoning action to clear wastes from the toilet bowl, the valve would be open during the flushing stage, causing the bowl to be flushed by hydraulic action.

On 11 April 1973, the NSF rejected Mr. Wilhelm's application, stating that "program limitations" prohibited funding of his proposal. There are no evident links between NSF's inability to assist Mr. Wilhelm and the subsequent development of his innovation. The proposal did not go through a formal review procedure at NSF, because Mr. Wilhelm had no "physical object" to test. Mr. Wilhelm has indicated that he could not have provided his own funds for cost-sharing, and would have been forced to go to other funding sources had the National Science Foundation offered assistance on a cost-sharing basis.

Particular barriers to development facing the individual inventor cited by Mr. Wilhelm include the difficulty of persuading someone to take a new idea seriously. Mr. Wilhelm was advised by friends to find a small firm that was imaginative and would take a risk with his product. Although unable to locate such a firm, he was contacted by many "invention agents," whom he ignored.

An important issue which plagued Mr. Wilhelm's innovation throughout its development was that of existing plumbing codes. Mr. Wilhelm insisted, however, that his invention lived up to the "intent" of the code, if not its literal interpretation. Current specifications, he suggested, were established in good faith by the equipment manufacturers, but before the "water crisis" in the nation, and the codes do not now reflect the real problems involved in water waste.

SeeAll Mirror

The title of Mr. Berman's proposal was "An Automobile Blind Area Eliminator." The SeeAll--as he called the device--consisted of a series of alternatively deviating and nondeviating strips of transparent, flexible, optical grade polyvinyl chloride (PVC). The function of the device, when applied to the glass near the roof supports in an automobile, was to present an image of those parts of the road normally blocked from the driver's view--the "blind spot"--on top of the normal view reflected in the mirror. The automobile driver, looking into his rear-view mirror, would see both an undeviated and a deviated image, reducing or eliminating his blind spot.

On 13 February 1973, NSF responded to Mr. Berman's proposal stating the the proposal was "found not to meet all the criteria for assistance. One of the principal requirements is that we be provided with something that can be tested."

Mr. Berman believes that the NSF Federal Laboratory Validation experiment was too limited in scope. He stated that evaluation testing, as designed in the project, does not provide enough assistance--that help is needed at all steps in the research and development process. In support of his opinion he mentioned a Swedish program for promoting innovation which is broader than the experiment at NSF. Mr. Berman believes, however, that criteria are needed before the government becomes involved in supporting a product in the private sector. These criteria should be based on engineering and economic criteria, and should include some assessment of a proposal's potential for commercial success.

A Coal Desulfurization Process

The process proposed by Dr. Winkler is protected by a patent awarded 1 November 1966. The purpose of the process is to reduce air pollution caused by the burning of high-sulfur coal.

The process is described as the grinding of coal with iron powder, whereby iron sulfide is produced and the sulfur content in the coal is lowered. The grinding takes place in a mixture of raw fuel oil, which itself may contain impurities, including a large amount of sulfur.

Dr. Winkler suggested to the National Science Foundation that testing be performed by Princeton Polymer Laboratories in Plainsboro, New Jersey. The laboratory is a private firm and was established by a group of polymer scientists and engineers to conduct contract research and development, market analyses, and market development. In a letter to Dr. Winkler on 20 February 1973, the firm stated that most of the test equipment needed to evaluate the coal desulfurization process could be available at Princeton Polymer Laboratories, however, the laboratory itself could provide no funds for the testing program.

Dr. Winkler met with Mr. E. Anderson at NSF on 14 February 1973. During a discussion of his proposal, an Office of Coal Research official was present and discussed the technical details of the necessary testing. However, because the validation assistance program as defined could not invest in capital equipment, NSF formally rejected Dr. Winkler's proposal on 12 April 1973.

Dr. Winkler supports the concept of governmental support of innovation. When old technologies become too expensive, new ways of accomplishing old tasks must be explored. Proposed new technologies must at least be evaluated--especially in an area such as energy--when the future costs of alternate resources may change radically.

Dr. Winkler pointed out that the criteria for providing government assistance should be based on the expertise and reputation of the scientist in question, and/or on the opinion of experts in the field. It is important, however, that "newcomers" be included in both the research and government communities. Dr. Winkler recommends that government invest during the early stages of the R&D process. On the other hand, he is quick to point out the federal investment in the marketing stage is not justified, and private enterprise should take over.

LaForce Car Engine

Edward LaForce claimed that the innovative car engine, for which he sought NSF validation assistance, results in additional horsepower with increased mileage by changing the way gasoline travels through the engine. The engine developed by the LaForces is basically a standard auto engine, burning gasoline inside cylinders to drive pistons, but the fuel system had been modified, as the LaForces claim, to burn gasoline more efficiently and completely. Edward LaForce had been in contact with several agencies, both federal and state, to obtain assistance in developing his innovation.

He contacted Mr. Norton Cushman of the Vermont Agency of Development and Community Affairs. Edward LaForce submitted a preliminary proposal to NSF through Mr. Cushman's office, thereby meeting the public sector requirement of the reoriented program. Automotive experts in the army and at EPA were contacted by NSF to assess the proposal. The army contact stated that LaForce was working in the right direction but doubted he could substantiate his claims and that if LaForce really had something, the automotive industry would be eager to become involved. EPA contacts stated that they had been in contact with the LaForces over a number of years, and that "the complexity of the changes were not commensurate with the potential results, which would not meet EPA's 1976 auto standards."

Edward LaForce never submitted a complete final proposal to NSF after he was requested to do so. Norton Cushman in Vermont apparently encouraged LaForce to get the proposal together, but this never occurred. Numerous tests have been conducted since 1974, but the company has met with financial problems, and the engine has never been marketed.

The NSF Project Officer pointed out that this case highlights the importance of clearly stated selection criteria and program requirements. Validation assistance was not provided for the LaForce car engine because no formal proposal was submitted to NSF. Further, due to the large number of tests conducted by other agencies, the confusion surrounding performance claims, and the legal difficulties of the Ventur-E Corp., it is fairly apparent that NSF assistance would have done little to increase the likelihood that the LaForce engine would reach the marketplace.

GENERAL FINDINGS AND CONCLUSIONS

The information related to the cases described and the data obtained from interviews with key persons, appears to address five general aspects of the validation assistance experiment. Specifically, these issues are:

- *Who should receive validation assistance?*
- *At which stages in the innovation process should assistance be provided?*
- *How should projects be selected for assistance?*
- *Where should the testing be conducted?*
- *How should the test results be used?*

Who Should Receive Validation Assistance?

The sample of projects reviewed includes innovations developed by individuals, small companies, and medium-size companies as well as two projects which were supported by public sector organizations. In general, it appears that:

- *Individual innovators or inventors and small companies can benefit most from a program designed to assist in validating the claimed performance of a new product or process*

- *The involvement of a public sector organization in the testing of a new product provides the individual inventor with access to a broad base of technical expertise, not otherwise available*

- *Public sector involvement in the verification of a product/process can increase the visibility of the innovation and increase interest among consumers*

It is interesting to note that none of the individual inventors requesting assistance obtained NSF funding, and none have been able to market their products/processes. On the other hand, three of the four medium-size companies not receiving validation assistance, have continued research and development activities or have marketed their products. Two companies which received funding (Alron and Ecquacon), both very small companies, have marketed their products to a limited extent.

From interviews with private inventors it is apparent that they simply do not have access to the capital necessary to conduct further research and development, conduct independent tests, and in most cases to build a functional prototype of their innovations. The small companies report that they are in a similar position since they do not have enough income from other marketed products to cover the research and development costs associated with developing a new product line. Further, they do not have a proven history of success, often a prerequisite to attract new venture capital.

Two projects, Transette/Georgia Institute of Technology and the Evapotranspiration System/Virginia Polytechnic Institute, suggest that the acceptance of a new product or process can be greatly enhanced by the involvement of the public sector. In addition to the obvious financial benefits of participating in this experiment (i.e., NSF cost-sharing) an individual inventor also gains access to a broad base of technical expertise. Since the patent rights remain with the inventor under the guidelines of the experiment, the inventor can freely interact with the personnel available at the involved public institution. These interactions often result in more immediate solutions to problems which occur during testing, thereby facilitating the timely and effective verification of the new product. For example, during the initial testing of the Transette system, it was found that some equipment was not operating properly. The problem was due to the use of inappropriate materials rather than errors in design. Through the cooperation of the inventor and GIT the parts were replaced and performance testing resumed with minimal delay. In short, the relationship between the public and private sectors appears to address a major concern of the private sector companies (i.e., Alron and Ecquacon) which were funded for validation assistance. That is, there is a need for a company representative to be present, on-site, to handle quickly any problems which might retard the progress of testing. Further, involvement of the public sector in the product verification program often generates considerable interest among potential consumers and investors. This is evidenced in the case of the evapotranspiration system, a process that has been known for some time, but which has not previously been systematically tested in a variety of environments.

At What Stage in the Innovation Process Should Assistance be Provided?

This experiment was designed to provide federal laboratory validation assistance only for testing the claimed performance of an existing article. No assistance could be provided for concept validation, product development, or marketing efforts. However, it appears that:

- *The individuals and small firms often need financial assistance in developing a workable prototype as well as validation testing*

- *The lack of assistance at the validation testing stage may be a major barrier to marketing innovations for individual inventors and small firms which lack financial resources*

- *The stage(s) at which federal support for innovations is provided, and the extent of that support should depend, in part, on the financial resources of the requesting firm/individual*

From Table 3 it can be seen that three of the four nonfunded projects proposed by private inventors were rejected because no prototype was available for testing. All three of these applicants stated that they could not afford the investment necessary to construct a prototype of their invention acceptable for formal testing. Furthermore, one of these innovations was a process (coal desulphurization), the testing of which would have required the purchase of several pieces of expensive capital equipment since an appropriate testing facility did not exist.

In three of the four funded projects, prototypes of the equipment were supplied for testing as the company's cost share of the project. However, in all cases testing was interrupted to some extent by equipment malfunctions. In short, these small companies could not afford the cost of refining or debugging the prototype prior to testing. The cases reviewed which involved medium-size companies suggest that these companies can market new product lines on their own. In three of the four cases (American Electronics Laboratories decided against further development of its textile inspection device) the companies had sufficient internal research budgets to continue product development without assistance from NSF.

In general, the stage in the research and development process at which individuals and small firms need assistance appears to differ from that of large firms with substantial capital assets. It is interesting to note that no further investments have been made in products developed by individuals and to date none of these innovations have reached the marketplace. Further, the cases studied suggest that the lack of assistance at the validation testing stage may not be so important for established firms with internal resources, since products proposed by these medium-size firms have been marketed.

From interviews with key personnel in the projects reviewed, it is clear that assistance is needed at all stages of the innovation process when individuals or small companies are involved. Further, assistance is most needed at the earliest stages of R&D, for it is then that firms, especially small firms, make the most conservative decisions regarding product development.

How Should Projects be Selected for Assistance?

There is considerable support for the requirements that funds be provided only for projects which are in the public interest and which have the potential for advancing the state-of-the-art. However, the restriction that the product/process validated will not be subject to subsequent tests for regulatory purposes remains open for discussion. From our observations and discussions with key personnel involved in the cases reviewed, it appears that:

- *Projects qualifying for validation assistance should be in the public interest and have the potential of advancing the state-of-the-art*
- *Test plans can be designed to determine if new innovations meet existing regulations, and to develop appropriate regulations where they are nonexistent, but needed*
- *Project selection can be objectively conducted by a panel of experts selected from potential testing facilities, not necessarily including the proposed testing site*

The provision of federal laboratory validation and the existence or lack of local, state, or federal regulations pose some complex questions about how regulations impact on the innovation process in the United States. In eleven of the twelve cases reviewed, regulations or the lack of regulations played an important role in the development of the innovation. The lack of codes or accepted industry standards appears to have had a negative influence on the development of several innovations studied. One innovator interviewed suggested that the lack of standards often serves as a disincentive for companies to innovate. The absence of standards, and the consequent lack of assuredness that potential consumers will use new products or techniques, can easily influence a firm's decision not to develop further an innovation. In other instances, however, the lack of regulations can serve as an incentive for innovation. When there is a complete absence of performance standards in a relatively new field, validation testing of a new product mav provide a marketing advantage to the innovating firm. That is, since industry often leads government in establishing specifications, nonexistent regulations or specifications established long ago and which often do not reflect the present situation, offer an opportunity for establishing new requirements on the basis of the performance of the new innovation.

When industry-wide standards do exist in the form of government-enforced regulations, these regulations may prohibit the development of particular innovations. It was suggested in several cases, that present standards may be too stringent, having been formulated in previous years and no longer reflecting the current situation facing a particular industry. It was pointed out, for instance, that the industry itself is often influencial in drawing up local, state, and federal regulations. Thus, when the intent of the original regulation can still be met but with new codes, the new codes may assist the development of certain innovations. The often conflicting codes for sewage and water processing equipment seem to be a case in point. These codes were established before the nation's present water shortages, and now may be requiring the use of excess water. New techniques might accomplish the same job while using less water. Since the presence or absence of regulations may serve as either incentives or disincentives to innovation, depending on the specific circumstances at hand, validation assistance for only those innovations not subject to regulations may not be a justifiable restriction.

This discussion is, of course, not exhaustive, and the results of the review clearly point to a need for further study of the relationship between regulations and codes, and the development of innovative products/processes.

Given that a set of selection criteria is identified, the question remains--who should determine if the criteria are met? It has been repeatedly suggested by those interviewed that a panel of experts from the specific field in question should determine if a given innovation is in the public interest and has the potential of advancing the state-of-the-art. Perhaps the best source of expertise for most technological areas is federal and independent laboratory personnel.

Where Should the Tests be Conducted?

In this experiment, federal laboratories have been the primary facilities used for implementing the testing protocols for new innovations. It should be noted that both federal laboratories and independent accredited laboratories were eligible to serve as testing sites. In our interviews it was repeatedly suggested that:

- *Selected test sites should have the appropriate facilities in-house*
- *Test sites should be easily accessible to the innovator, to facilitate cooperation between the designer and test engineers*
- *Federal laboratories are an excellent choice for testing sites since they often have needed expertise and equipment*
- *A validation assistance program could benefit greatly from the expertise available in independent laboratories as well as federal facilities*

While the cooperation of federal laboratory personnel was very good, both in reviewing proposals and conducting tests, it is clear that validation testing per se is an activity which is in conflict with the stated laboratory missions of research and evaluation. Further, since federal laboratory personnel perceive themselves as scientists rather than technicians, conducting tests of new innovations without an evaluative component is not typically considered a priority task.

Given this potential conflict of interests, independent laboratories offer a viable alternative as test sites. The American Council of Independent Laboratories, Inc. includes a wide variety of facilities located throughout the United States. These proprietorships or corporations typically include testing as part of their mission statement and are therefore particularly suited to participation in the Federal Laboratory Validation Assistance Experiment. Further, the fact that these laboratories are located in virtually every state, affords the opportunity to select a test facility which is reasonably close in proximity to the innovating company/individual. Close geographic proximity would allow more consistent and timely interaction between laboratory personnel and innovators. The need for such a close working relationship has been emphasized during our interviews with innovators, and the success of the testing program for the Transette project, to some extent substantiates the importance of continued interaction between an inventor and personnel at the test site.

How Should Test Results be Used?

The experiment as designed required that a "test protocol" be signed between the testing agency and the innovator/firm. The protocol required that the innovator, when citing the federal laboratory validation test, use the entire report from the testing laboratory; no parts of the test results could be used independently of the complete report. It appears that:

- *The intent of a validation plan must be clearly specified*
- *Test results should be reported in non-scientific language, to the extent possible, to increase the utility of findings to the innovator for marketing purposes*
- *Results of the validation of claimed performance should be conducted and reported separately from the results of tests conducted for research and development purposes*

This requirement played an important role in at least one of the funded projects reviewed. The firm wanted to use those parts of the test which referred to the claimed performance of its proposed product, and not those parts of the tests which addressed additional performance parameters of the product for which no claims were made. Despite equipment breakdowns and subsequent difficulties in collecting data from the tests, those claims made by the firm for the product were, in large measure, verified. However, the laboratory upon request had also performed other series of tests on the equipment, and these tests produced negative results. Since the entire report of test results had to be cited if any portion of the findings were used in a marketing campaign, none of the data were used by the firm.

In general the firm felt that the test results report from the laboratory was too complex for persons not familiar with the scientific jargon used. While the firm needed validation of its product, validation of claimed performance accompanied by negative results on other tests couched in scientific terms prohibited the use of the report in attracting capital and in marketing efforts. It was suggested that a different reporting procedure whereby test results relating to claimed product performance might be conducted and released independently of a more comprehensive, exploratory testing program, and might do much to increase the utility of validation testing findings.

SECTION II.

An Analysis of the National Science Foundation's Innovation Centers Experiment

This description of the Innovation Centers Experiment was prepared by the Research Triangle Institute for the National Science Foundation; R.M. Burger is the author. The content is based on reports and other material provided by the directors of the three centers and by R.M. Colton, the NSF Program Manager, and on interviews with persons who have had contact with, or knowledge of, the centers. Mr. Colton has, in addition, reviewed this report and concurs as to the authenticity of the data. Any opinions, findings, and conclusions or recommendations are those of the author and do not necessarily reflect the views of the National Science Foundation or of the Innovation Centers.

An Analysis of the
NATIONAL SCIENCE FOUNDATION'S INNOVATION CENTERS EXPERIMENT

an effort to promote technological innovation and entrepreneurship in academic settings

32

PREFACE

The Innovation Centers Experiment is part of a continuing effort by the Federal Government to test and evaluate unique institutional arrangements for stimulating technological innovation in the private sector. The suitability of replicating these institutions as a public policy is judged by a number of criteria including: importance of the problem being addressed and the leverage and effectiveness of the solution posed; the costs, legal aspects, equity, understanding, acceptance, and administration of the policy for replicating the institution and the hypothesis, design, and feasibility of the experiment used to develop and evaluate the institution.

As the experiment is reaching its end, it has shown a great measure of success from both a performance standpoint and in satisfying the posed criteria.

The data included in this report substantiates this conclusion. It is anticipated that data collected in the future will continue to show Innovation Centers as a suitable institutional arrangement on which to base a national policy.

R. M. Colton
July 1977

SUMMARY

Innovation Centers, sponsored by the National Science Foundation at three universities, have outstanding interim results to report. These Centers have:

- participated in the creation of over 30 new ventures, of which 23 have achieved sales in excess of $30 million, have resulted in approximately 1,000 new jobs, and have generated in excess of $6 million in tax revenues;
- exposed over 2,000 students to instruction and/or experience in the entrepreneurial, invention, and innovation processes; and
- assisted in the evaluation of over 2,000 ideas for new products.

These Innovation Centers comprise an experiment, the objective of which is to determine whether the entrepreneurial tendencies of students can be enhanced by participation in academic coursework and clinical experience provided in the university environment. While early results indicate success, definitive conclusions relative to the objective will be determined only after tracking the careers of the participating students.

The interim results listed above arose directly from Innovation Center operations in pursuit of the broad objective. Functions involved in these operations included:

- idea/invention evaluation,
- assistance for new business startups,
- development of new products for existing businesses,
- formulation of innovation/entrepreneurship education curricula,
- research on the innovation/entrepreneurship processes,
- participation in entrepreneurial decisionmaking.

The demonstration and propagation of such activities is essential to the continued economic vitality of the American economic system. The past successes of this system have been based on innovation and entrepreneurship—in production, agriculture, technology, and science—but this success has resulted in a social/economic/governmental structure tending to suppress those very attributes that created it. The Innovation Centers seek to counter this trend.

Despite the absence of long-term results, it is difficult to avoid the conclusion that the Innovation Centers have demonstrated outstanding success through the interim results cited above. The measures of this success may be depreciated: (1) some of the new ventures may have come into being without Innovation Center involvement, (2) production and jobs may not be net gains due to the displacement of existing products, (3) the Innovation Centers may have a marginal impact on many of the students, and (4) idea evaluation is a difficult to assess benefit. But ventures have been created, students have become entrepreneurs, and ideas have been commercialized successfully as a direct result of the Centers' efforts.

Each of the existing Innovation Centers at MIT, Carnegie-Mellon University, and the University of Oregon are organized differently, have a unique emphasis, and produce different products. Each is successful in its own way and appears to have a good chance for continuation past the period of NSF support. The experiment runs 5 years and terminates in 1978. After that, the Centers must become self-supporting or attract other support. In any case, it appears that the type of functions being performed by the Innovation Centers will continue in the academic environment. Other universities are emulating the Centers and are becoming increasingly aware that they can and should engage in such activities.

TABLE OF CONTENTS

SUMMARY
v

INTRODUCTION
1

PROBLEM
3

PLAN
7

PROGRESS
9

PRODUCTS
15

PROGNOSIS
26

APPENDIX
27

INTRODUCTION

At MIT, students are developing TV games, electronic guitars, and ignition systems; at Carnegie-Mellon University, students are participating in business ventures in medical instrumentation, computers, newspapers, and prosthetics; and at the University of Oregon, hundreds of inventors are being aided in the evaluation and promotion of their ideas. These activities are not in the traditional mold of the university but are part of a National Science Foundation experiment aimed at promotion of innovation and entrepreneurship. This experiment responds to a need in the United States to actively foster the basic ingredients that allow a free technological society to retain its vitality in an increasingly structured environment.

The Innovation Centers experiment has been underway for 4 years and is producing an increasing flow of innovations, inventions, and entrepreneurial activity. The experiment shows much promise for demonstrating the efficacy of its methods and although it may not be a panacea for the general problem (there is none), this effort holds promise for helping to reverse the trend away from entrepreneurship. This report examines the experiment and its results.

The National Science Foundation began the Innovation Centers Experiment in 1973 in order to assess the ability of universities to nourish a very practically oriented effort to increase American entrepreneurship and innovation. This experiment is still underway and the final results are yet to be determined. Now, however, there are useful lessons to be derived from the experience in establishing and operating the Innovation Centers, from the mechanisms employed in carrying out the experiment, and from the interim results being obtained. Here, the experiment is described and an attempt is made to present its essence.

The objective of the Innovation Centers as stated by the NSF Program Manager is "to determine if the combination of formal classroom training in engineering and business theory and hands-on clinical experience in generating new ideas, developing and evaluating new products, and initiating new ventures can increase . . . the probability of the . . . participants becoming successful entrepreneurs."* The experiment thus couples innovation (the act of introducing something new or novel), the entrepreneur (one who assumes the risk and management of business), and a clinic (where special problems are studied by concrete examples with expert advice), with the university (an institution organized for teaching and study in the higher branches of learning). The fruit of this union is envisioned as an innovation in itself, a new process for instilling vigor in

---

*R.M. Colton, "Technological Innovation through Entrepreneurship" (to be published).

The New York Times, Thursday, November 26, 1976

LOSS OF INNOVATION IN TECHNOLOGY IS DEBATED

by Walter Sullivan

American innovation and ingenuity have lost their momentum, the chairman of the President's Committee on Science and Technology told the National Academy of Engineering in Washington last week.

Use of science and technology for the Nation's benefit is, he said, "less bold, less innovative, more timid."

The speaker was Dr. Simon Ramo, cofounder of the Ramo-Woodbridge Corporation . . . .

a sluggish economy lethargized by its unwieldy structure—an injection of creativity directed to practical needs. It is not obvious that the coupling of such disparate elements should be fruitful; thus, the experiment.

As the experiment and its results are described, evidence will be cited that indicates that the Innovation Centers Experiment is a success, that a pattern has been established for widespread adoption, and that there are a number of potential beneficiaries including:

- students and others with aspirations for becoming entrepreneurs;
- educators who wish to provide entrepreneurship opportunities for students;
- entrepreneurs who require assistance;
- policymakers and legislators concerned with innovation, productivity, entrepreneurship, economic stimulation, and innovation;
- inventors requiring evaluation of their ideas;
- venture capitalists interested in growth opportunities; and
- industries requiring new products.

This is documented in the descriptions of the problem-plan-progress-product-and-prognosis that follow.

PROBLEM

In the United States, there is a tradition of innovation, invention, and entrepreneurship to which is ascribed a large measure of the Nation's success in achieving its political and economic success and thus a desirable "quality of life" for its citizens (see figure 1). Over the last decade, concerns have been expressed that these basic ingredients are disappearing from the American scene and that the consequences will be an erosion of this country's leadership in the world. These concerns are substantiated by data on inventions, new ventures, trade balances, technological development, and productivity. Although the causes and cures relating to the decline of the technological entrepreneur will be sought in many forms for many years, the search for responses cannot be, and is not being, deferred.

Barriers to innovation and entrepreneurship have been documented. Williams et al.[*] identify key barriers that include the limitations of available technology, the inability to match needs and capabilities, the unyielding structure of markets and supply systems, the size of the financial risks and rewards, the rigidity of institutional and intellectual patterns, and the inability of available organizations to mount sustained efforts to meet needs.

The status of the technology barrier depends on the vigor of research in various fields (see figure 2). The other barriers are direct derivatives of our socioeconomic structure and yield only under the pressure of that structure. But they are only barriers and are susceptible to circumvention.

However one may view these barriers, it is a fact that innovation in the United States has decreased to a dangerous extent. The U.S. Patent and Trademark Office reports patent award data indicating that U.S. patents awarded to foreign inventors exceed those awarded to U.S. inventors by a wide margin in several special areas[†] and, across the board, the ratio of foreign to domestic patents is rapidly increasing (see figure 3). Gee and Tyler[‡] have reviewed barriers to innovation with particular emphasis on the regulatory and bureaucratic impediments and also draw convincing links between the reduction in innovation and a declining rate of growth in U.S. productivity (see figure 4), the shrinking

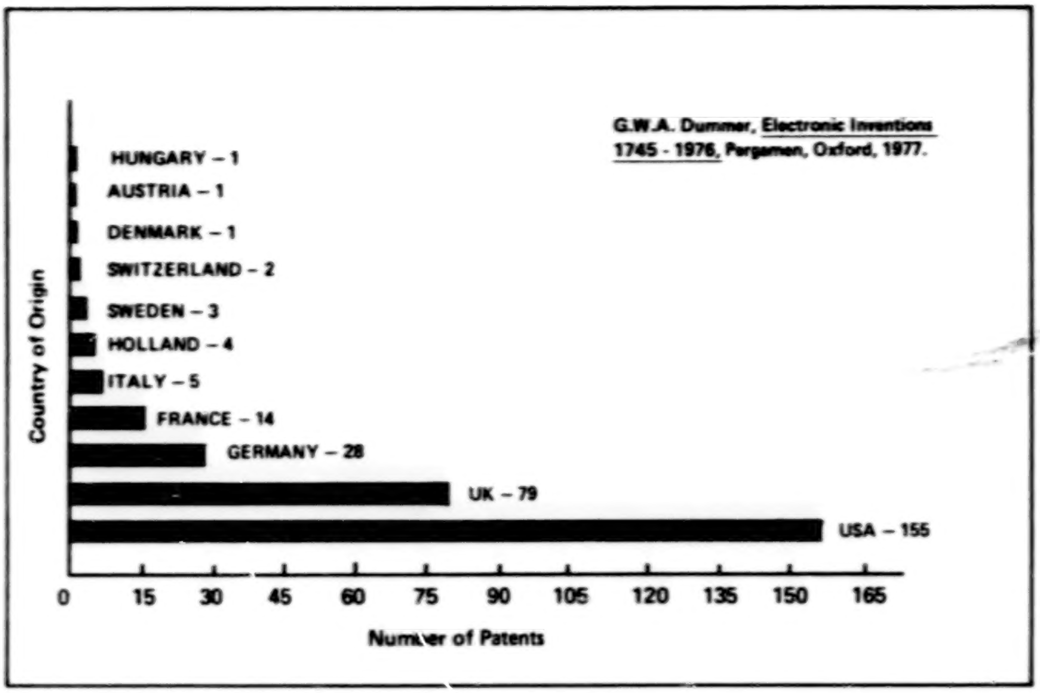
---

[*] C. Williams, E. Milbergs, R. Quick, and J. Ford, ***Planning and Evaluation Assistance to the NSF Experimental R&D Incentives Program,*** Stanford Research Institute, Menlo Park, California 94025, June 1973 (Contract URU-72-66, RDI Report No. 17).

[†] ***Technology Assessment and Forecast, Sixth Report.*** U.S. Patent and Trademark Office, Washington, D.C. 20231, June 1976 (PB-254-188).

[‡] E.A. Gee and C. Tyler, ***Managing Innovation***, John Wiley, New York, 1976.

BEST DOCUMENT AVAILABLE



G.W.A. Dummer, Electronic Inventions 1745 - 1976, Pergamon, Oxford, 1977.

Figure 1. Countries of origin of electronic inventions (Europe and U.S.A.).

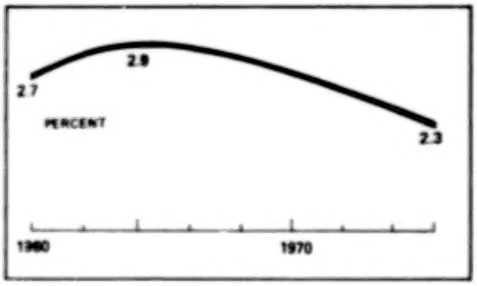


Figure 2. R&D as percent of gross national product.

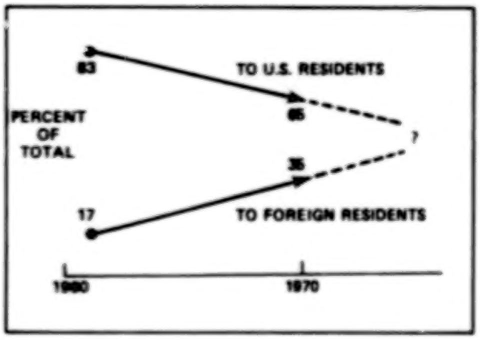


Figure 3. U.S. patents.

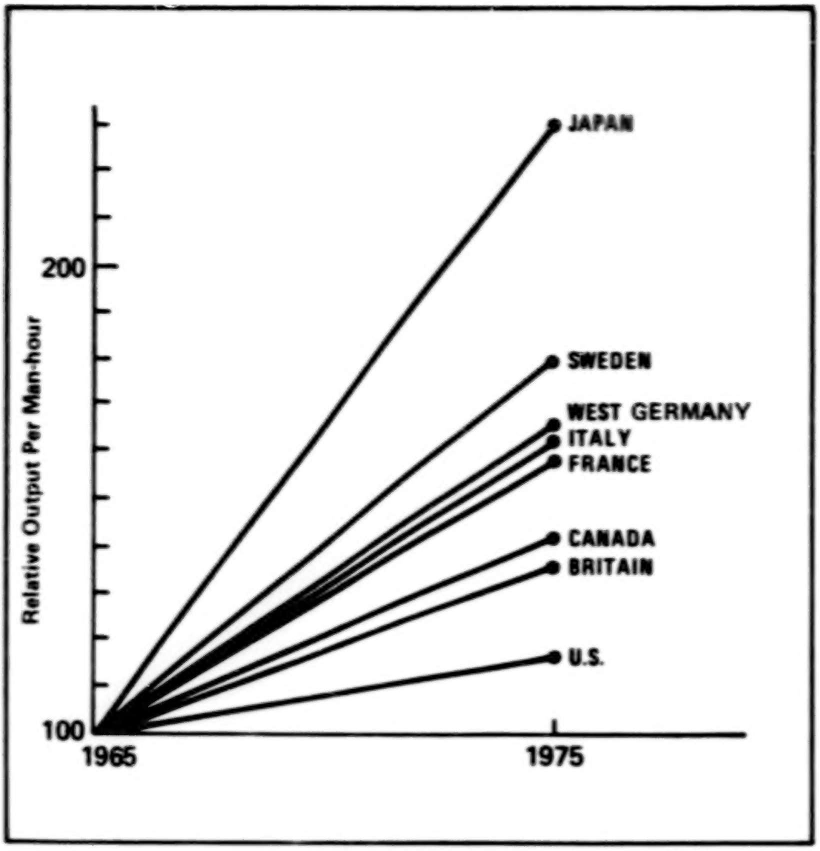


Figure 4. Productivity output per man-hour
(indexed to 100 for 1965).

U.S. share of the world Gross National Product (see figure 5), and trade deficits. *Business Week*[*] reports a growing concern with the erosion of innovation that bodes ill for this Nation's political and economic future. Noting that for an economy built upon innovation, the implications of a technological slowdown are stupendous.

The fact that innovation is inseparable from entrepreneurship was indicated in a study of major innovations.[†] This is logical since innovation requires change and change in any form requires risks. Thus risk takers or entrepreneurs are required who perceive both the risks and rewards in innovation, and are willing to gamble on their judgment in risk-taking. The trend has been toward a decreasing number of U.S. entrepreneurs. The need is for *more*—and this is the need to which the Innovation Centers Experiment is directed.

---

[*] "The Breakdown in U.S. Innovation," *Business Week*, p. 56, February 16, 1976.

[†] S. Globe, C. M. Schwartz, and G. W. Levy, "Final Report, Interaction of Science and Technology in the Innovative Process: Some Case Studies," Battelle Columbus Laboratories, Columbus, Ohio, 1973 (NSF-C-667).

BEST DOCUMENT AVAILABLE

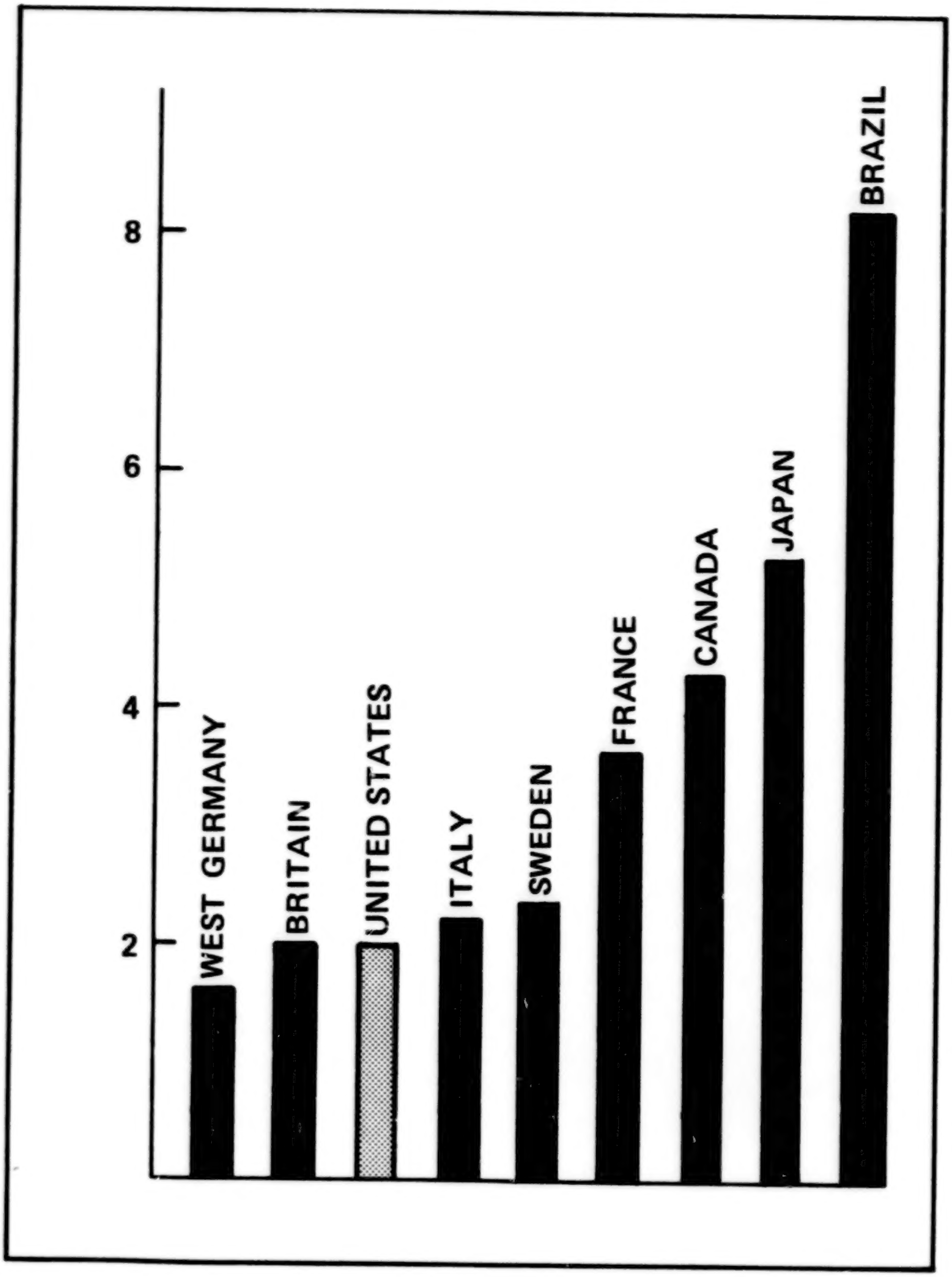


Figure 5. Average annual growth in G.N.P. (1970–1975).

PLAN

With the need defined—more entrepreneurs—the next step is to find a way to meet this need. Logic leads to the supposition that most success will be obtained with students whose career choices are changable. The chosen approach was "to create an atmosphere that allows failure without negative consequences ..., students are free to fail as well as to succeed" in the words of Robert Colton, the NSF program manager. Thus the stage was set to begin an experiment in academic settings that would test various methods for increasing the entrepreneurial tendencies of students who participate in the experiment.

The background for the Innovation Centers Experiment may be traced to 1968 when Congress, responding to a need for increasing the relevance of research, authorized the National Science Foundation to undertake applied research. Among the several responses to this distinct change in the Foundation's charter were the establishment of RANN (Research Applied to National Needs) in 1971 and of the Experimental R&D Incentives (RDI) Program in 1972. The RDI objective was to identify and test incentives to stimulate technological innovation. In early 1973, R. Colton and A. Ezra responding to the objective of the RDI program developed the Innovation Center concept and designed an experiment to test its efficacy. This experiment was one of seven such RDI experiments initiated in 1973 and 1974.

In brief, studies had indicated that the major factor in technological innovation is the entrepreneur and that contemporary socioeconomic patterns suppressed rather than encouraged entrepreneurial tendencies. Innovation Centers were conceived as vehicles within universities for stimulating technological innovation and for increasing the entrepreneurial tendencies of graduates as they pursued their careers. Both formal education and clinical experience in innovation invention, and entrepreneurship, would be included in the Center activities.

Concomitant but subsidiary objectives of Innovation Centers include providing support for the independent innovator or entrepreneur, increasing non-Federal investment in research and development, and accelerating the commercialization of innovations (see figure 6).

The Innovation Centers Experiment was designed so that Government support for the Centers would terminate after 5 years. At that time, the viability of the Centers would be demonstrated if they become self-sustaining and if they become models for further efforts to promote innovation and entrepreneurship.

The RDI Program and RANN—initially separate thrusts—have merged, and the Innovation Centers Experiment is now under the aegis of the Industrial Programs area of the RANN Division of Intergovernmental Science and Public Technology.

43

BEST DOCUMENT AVAILABLE

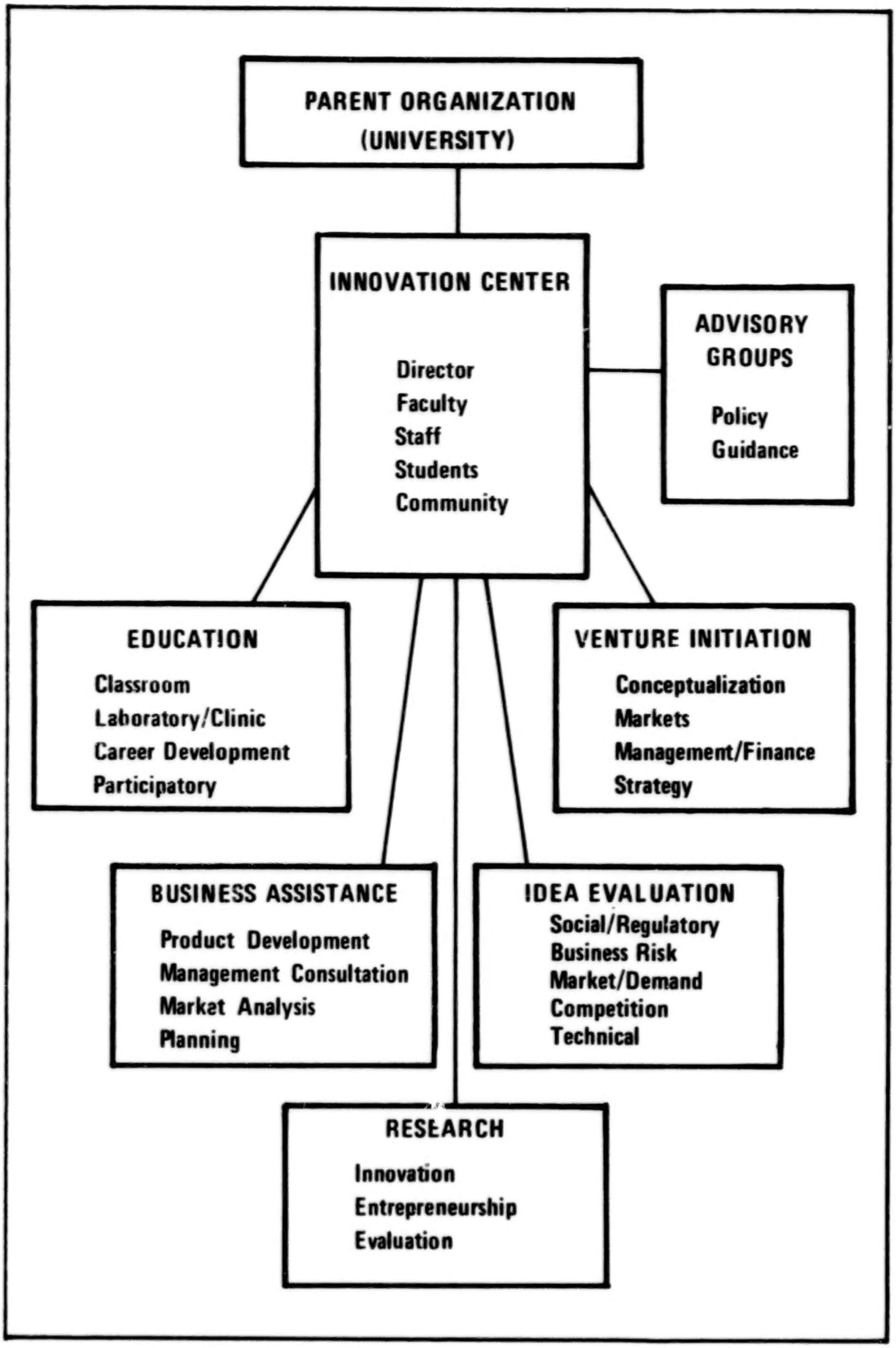


Figure 6. Innovation Center concept.

PROGRESS

INCEPTION—After the conceptualization of the Innovation Centers Experiment in early 1973, events moved rapidly. The experiment was established and fully funded by June 1973. In that same month, three centers were established and awarded a total of $3 million for 5 years of operation. These three centers were selected, with the concurrence of the National Science Board, from six formal proposals that, in turn, had been chosen from 12 original informal proposals. An important innovative instrument employed in the experiment is the Cooperative Agreement that replaces the normal grant or contract. This agreement provides for the university and the National Science Foundation to work together to achieve the purposes of the Innovation Center. The Cooperative Agreement sets the stage for continuous interaction of the Program Manager, R. M. Colton, with each of the Centers. Special provisions were included that encouraged the Innovation Centers to derive income from their activities; for example, both inventors and the Centers could share in rights to patents developed in the course of Center activities. *The stability obtained by 5-year funding, the flexibility derived from the Cooperative Agreements, and the continued involvement of NSF in the experiment have had significant positive impacts on the results.*

The Innovation Centers were established at Carnegie-Mellon University (CMU) in Pittsburgh, the Massachusetts Institute of Technology (MIT) in Cambridge, and the University of Oregon (UO) in Eugene. The experiment was structured in two phases. Phase I which was to last about one year would include the finalization of a viable operating plan, and the formulation of a method by which the success of the Center could be ascertained. Phase II, the operational phase, was to be initiated after NSF acceptance of Phase I and would continue throughout the experiment. By late summer of 1974, all of the Centers had completed Phase I of the experiments and, with the subsequent approval of these results by NSF, had begun the operational phase.

OPERATIONS—Each of the Innovation Centers has as a common objective the demonstration that university-based activities can stimulate innovation and entrepreneurship in the external business community. *Each of the Centers combines education, clinical exposure for students, research, and outside business/inventor assistance in driving toward this objective.* But beyond these commonalities, each Center has a distinct emphasis that sets it apart. This distinctness is derived from the varying institutional settings and investigator perceptions. It provides an experiment within the Centers experiment that defines the relative benefits of the different approaches.

Innovation Center
Prof. Yao Tzu Li
Massachusetts Institute of Technology

At MIT, the central purpose of the engineering school-based Innovation Center is to provide a supplemental education program in which various disciplines are linked to enhance the entrepreneurship ability in participating students. The teaching methodology stresses direct participation of students in innovation including the risk-taking and rewards that are inherent to the process. The Innovation Center has two primary branches, the Innovation Education Program and the Innovation Co-op.

The Innovation Education Program provides an opportunity for students, who do not have time to become involved in the "learn by doing" process, to obtain the distilled experience of the entrepreneurial activities. This is centered in five core courses: Introduction to Innovation, Invention, Entrepreneurship, Invention Development Laboratory, and Internship in New Enterprise Development. In the fall of 1976, 104 students were enrolled in these courses.

The Innovation Co-op includes three programs: the Entrepreneurial Development Program, the Industrial Product Development Program, and the Invention Development Program. In the Innovation Center the ultimate goal is to give students the opportunity to follow the entire product development cycle from conception to the marketing of the product. This Entrepreneurial Development Program is a time-consuming and expensive process. Two companies have been founded by this process: Computer Controls Corporation and Hetra Inc. Their products are a computer-controlled heating, ventilating, and air conditioning system, and a precious metals-identifying instrument, respectively.

In the Industrial Product Development Program, product needs are identified by an industrial firm and students and faculty seek innovative products to fill the needs with sponsorship by the industry. Two products resulting from such efforts are a TV tennis game and an automotive ignition system.

The Invention Development Program provides for the evaluation and development of promising inventions. Emphasis is on overcoming both technical problems and on the severe obstacles encountered in reaching the marketplace. An electric guitar, a high performance bow, and a small molecule detector have resulted from this program.

The continued viability of the Center depends on its development of income from royalties, industrial sponsorship, and government contracts and on institutional support. Funding for the Innovation Center is also to be included in the education fund-raising activities of MIT. Over $150,000 in income from royalties and $350,000 in contracts are budgeted for FY 1978. The continuation of the Innovation Center beyond the period of NSF support appears assured.

46

At the MIT Innovation Center, which is based in the School of Engineering, the focus is on the evaluation and maturation of ideas. In its most recent year, the Center received 139 ideas for evaluation from outside the Center. However, the majority of ideas that receive detailed attention originate with MIT students and faculty because of the desirable direct involvement of the originator with idea development. Ideas are evaluated and developed either in the Innovation

Center for Entrepreneurial Development (CED)
Prof. Dwight M. Baumann
Carnegie-Mellon University

CED operates from an academic base that includes the engineering school, Carnegie Institute of Technology; the Graduate School of Industrial Administration; and the School of Urban and Public Affairs at Carnegie-Mellon University. It is unique among the Innovation Centers in that CED is a separately incorporated non-profit organization affiliated with, and effectively a subsidiary of, the university. Its objective is to encourage and develop entrepreneurial activities through education, research, and support of new venture.

The educational efforts of CED are effected through the academic departments of the university wherein both graduate and undergraduate students have the opportunity to participate. Emphasis is on an engineering design program wherein graduate students participate in actual entrepreneurial activities. In 1975, some 20 faculty and 90 students were associated with these activities.

The focus of CED is on the entrepreneurial process and new business startups. In its first year, three companies were helped: Compu-Guard Security System, Inc.; Sun Publications, Inc.; and Three Rivers Computer Co. By the latter part of 1976, CED had been involved in the startup of a total of 11 companies, the largest of which has an order backlog of $10 million and has 43 employees. Annual sales of the companies exceeded $3.5 million in 1976. In late 1976, CED was involved with eight new business projects and was evaluating many good ideas. It is noted that new business ventures are more limited by a shortage of technological entrepreneurs than of inventors.

The continuation of CED as a self-sufficient Innovation Center, by the operating plan, is dependent on repayment of loans, and on ownership interest in the new ventures. However, the time scale for nurturing an idea to the point where it becomes a business venture and for a new venture to reach a level of profitability to where it can repay the investment is so lengthy that there may be a transition problem at the termination of NSF support. The successes of CED, the early emphasis that it placed on creation of a viable institutional setting, and its vigor in pursuing new opportunities indicate a high probability for continued successful operation.

Education Program or in the Innovation Co-op. In the Co-op, the ultimate product may take any one of three forms: a new company with a new product in which students or former students are the entrepreneurs, a new product developed in response to a specific industry need and with industry support, or a developed invention to be licensed to an existing business. However, overall emphasis is on education with coursework and student instructional laboratories coordinated with the more clinical environment of the Innovation Co-op.

The Center for Entrepreneurial Development (CED) at Carnegie-Mellon University serves as a "maternity ward" for new business startups with a focus on technology transfer through entrepreneurship. It is based in the schools of

Experimental Center for the Advancement of Invention and Innovation

Dr. Gerald G. Udell
University of Oregon

The principal thrust at the Oregon Innovation Center is invention evaluation based on the premise that this is one important way in which universities can stimulate inventors, innovators, and entrepreneurs. To this end, much emphasis has been placed on the development of an idea or invention evaluation system in close cooperation with the Western Inventors Council, over 12 industrial concerns, and a number of universities and agencies. In its most recent reporting year, the Oregon Innovation Center received 244 ideas, innovations, or inventions for evaluation.

In addition to its evaluation activity, a full spectrum of education and entrepreneurial encouragement activities are maintained. In the curriculum of nine courses, 510 students were enrolled in the 1975-76 academic year. Graduate student participation in center activities is increasing. Activities include teaching, consultation, research, and curriculum development.

Many innovations evaluated at the Oregon Innovation Center have been patented. From the 30 or so patents, examples range from portable electric ovens and laser printers to a high rise solar/wind collector. A number of reports have been issued on the evaluating process, and during the latest year four new ventures were formed; for example, one is attempting to commercialize a therapeutic knee exerciser.

The original goal of the Oregon Innovation Center was to be self-supporting from the fees charged for idea evaluation and from venture income or royalties by the end of the NSF-supported experimental period. The experience with the incubation of new ventures has indicated that this is not practical; however, through its performance, a constituency is being developed through which continued support may be derived.

engineering, business, and urban and public affairs. The CED emphasis on entrepreneurship leads to its providing financial services, laboratory facilities, and other resources for university-derived, technology- or research-based new businesses. The university environment is seen as providing a constant stream of potential innovations. CED, through the teaching of entrepreneurship and its study of barriers to innovation, attracts and encourages potential entrepreneurs. When a technological entrepreneur and his idea are considered viable, CED becomes actively involved in the creation of a business. The incorporation of the Center as a nonprofit entity for investing in new enterprises and for sharing in their success is viewed as an essential element in making entrepreneurship an important activity in the academic community.

The plight of the independent inventor is the primary concern of the Oregon Innovation Center. Its academic and educational programs are in the College of Business Administration. Working in close cooperation with the Western Inventors Council, the Oregon Center's outreach extends more to inventors outside of the academic community than do the other two centers. Early emphasis

Societal Factors

Legality
Safety
Environmental Impact
Societal Impact

Demand Analysis Factors

Potential Market
Potential Sales
Trend of Demand
Stability of Demand
Product Life Cycle
Product Line Potential

Competitive Factors

Appearance
Function
Durability
Price
Existing Competition
New Competition
Protection

Business Risk Factors

Functional Feasibility
Production Feasibility
Stage of Development
Investment Costs
Payback Period
Profitability
Marketing Research
Research and Development

Market Acceptance Factors

Compatibility
Learning
Need
Dependence
Visibility
Promotion
Distribution
Service

Figure 7. Invention evaluation.

was on the development of an invention evaluation system that identifies ideas that promise commercialization success. For the relatively few promising inventions from the many submitted (244 in latest year), the Oregon Innovation Center offers the inventor assistance at whatever level is required in return for participation in future profits and royalties. Contacts with industry, government agencies, and others are cultivated to help in invention development and commercialization. Thus the largest effort has been invested in development of an effective and efficient means of evaluating new ideas and transferring technology to the end of stimulating inventors, innovators, and entrepreneurs (see figure 7).

The three Innovation Centers are thus operating entities. Some 25 academic courses, 700 students, and 54 faculty members are associated with the Innovation Centers (see the appendix). An evaluation of the progress being made toward the prime objective—increasing the number of students who become successful entrepreneurs—is not yet possible. It will come with time. At this time, the success of the Innovation Centers must be measured in terms of interim products and subsidiary goals. These are presented in the next section.

PRODUCTS

The Innovation Centers Experiment has obtained visibility, is producing results, and appears at this time to be a success. The nature of the experiment, its broad objectives, and the stature of the universities that host the Innovation Centers by themselves create a positive aura. A firmer substance is being given to this appearance of success by the statistics associated with the experiment—that of students, ventures, inventions, and flow of ideas. Interviews with people who have had contact with the Centers reenforce this finding as do the proliferation of emulators at other universities. But all of this evidence does not really demonstrate the success of the experiment; it only proves that something good is being done. The success of the experiment will only be proven when the entrepreneurship of the student participants is shown to exceed that of a control group. NSF plans to track the participants over a period of several years to obtain this data and thus to measure the effectiveness of the experiment. In the meantime, the interim results can be examined and used.

EDUCATION OBJECTIVES—Carnegie-Mellon, MIT, and Oregon were teaching courses in innovation and entrepreneurship before the Innovation Centers Experiment began. During the course of the experiment, the number of students has expanded from 400 to 700 and the number of courses offered each year has increased from 14 to 30 (see figure 8). The courses that are in the curricula are listed in table 1.

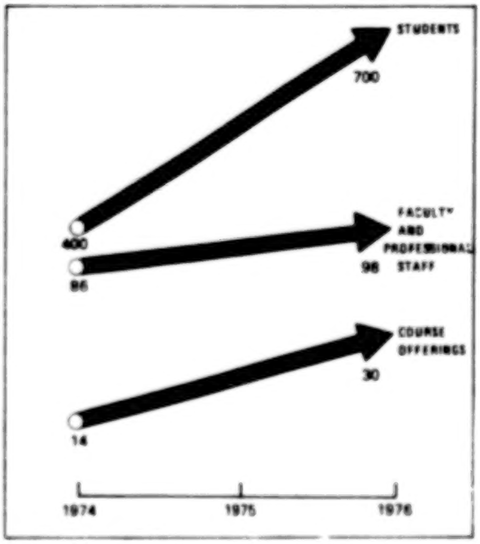


Figure 8. Educational activities of innovation centers are increasing.

Table 1. Courses Associated With Innovation Centers

University of Oregon
- Small Business Management
- Venture Finance
- Management and Innovation
- Entrepreneurship
- Management Research and Development
- Applied Innovation I
- Applied Innovation II
- Marketing Innovations

Carnegie-Mellon University
- Small Business Problems
- Design and Entrepreneurship
- Management of Technological Innovation
- Engineering Economics
- Management Strategy

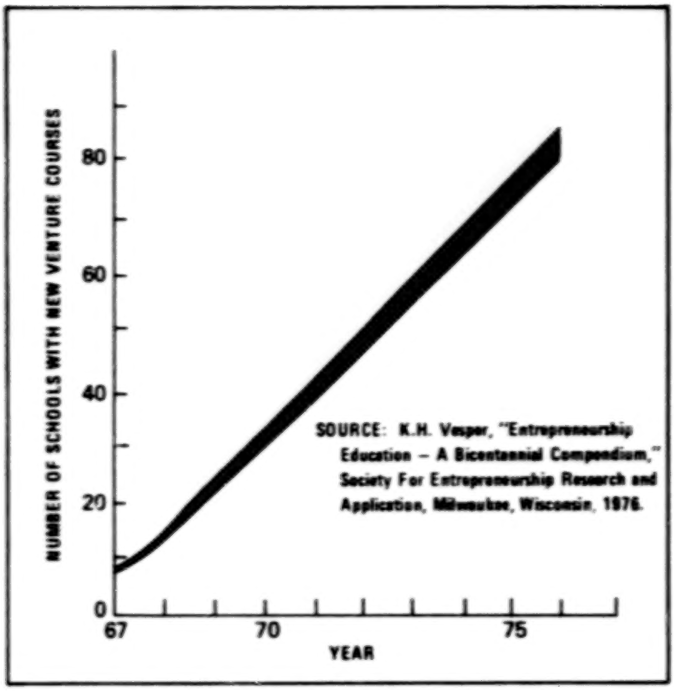
Massachusetts Institute of Technology
- Introduction to Innovation
- Invention
- Entrepreneurship
- Invention Development Laboratory
- Internship in New Enterprise Development
- Invention and New Enterprise Seminars
- Innovation Project Seminars
- Marketing New Products
- Innovation Workshop for Industry

The introduction of innovation and entrepreneurship offerings for students in universities is not without difficulties. The discipline-oriented and crowded curricula in the conventional university departments compete for students and are not receptive to interdisciplinary or nontraditional courses. Dr. Li at MIT has supported the Innovation Education Program with NSF funds and, in the Engineering School, has provided a homogeneous and strong course offering. He has argued eloquently for the important role of these courses as a supplementary education program. Despite an apparent reluctance of other faculty members to encourage students to take the Innovation Education Program courses, enrollment has grown and the innovation curriculum is becoming a permanent university-supported program.

In similar fashion, a strong set of courses in innovation and entrepreneurship has become a part of the curriculum of the College of Business Administration at Oregon. In the latest reporting year, 510 students enrolled in these courses, for an increase of 25 percent over the previous year. At Carnegie-Mellon less emphasis is placed on special courses. The educational objectives are met primarily by the existing curricula of the involved schools.

K.H. Vesper has tracked entrepreneurship education at American universities and reports that upward of 80 schools now offer such courses as compared

BEST DOCUMENT AVAILABLE



SOURCE: K.H. Vesper, "Entrepreneurship Education – A Bicentennial Compendium," Society For Entrepreneurship Research and Application, Milwaukee, Wisconsin, 1976.

Figure 9. Growth of entrepreneurship education.

to only 10 a decade ago.* (See figure 9.) During the period of the Innovation Centers Experiment, this number has increased by one third. It would be erroneous to ascribe this to the Innovation Centers directly, although there is evidence that many schools have been influenced by the experiment.

VENTURE INITIATION—At the beginning of the Innovation Centers Experiment, prior activities at MIT and Carnegie-Mellon had resulted in venture activities, the needs of which were rapidly responded to by the embrionic Innovation Center. Successes were realized.

At CED, for example, a company, Compu-Guard, had been formed in 1972 by two Carnegie-Mellon graduates, Romesh Wadhwani and K. Pribadi. At critical points in its development, Compu-Guard was provided with various types of assistance by CED including a direct loan and help in securing contracts and venture capital. Compu-Guard now has $3 million in annual sales, a $10 million order backlog, and 40 employees including 8 additional Carnegie-Mellon graduates. It manufactures and sells electronic computer-controlled security and energy management systems (see figure 10).

---

*K.H. Vesper, ***Entrepreneurship Education—A Bicentennial Compendium***, Society for Entrepreneurship Research and Application, Milwaukee, Wisconsin 1976 (supported by National Science Foundation).

BEST DOCUMENT AVAILABLE

Figure 10. Compu-Guard Personal Communicator that transmits a signal to a central receiver in an emergency.

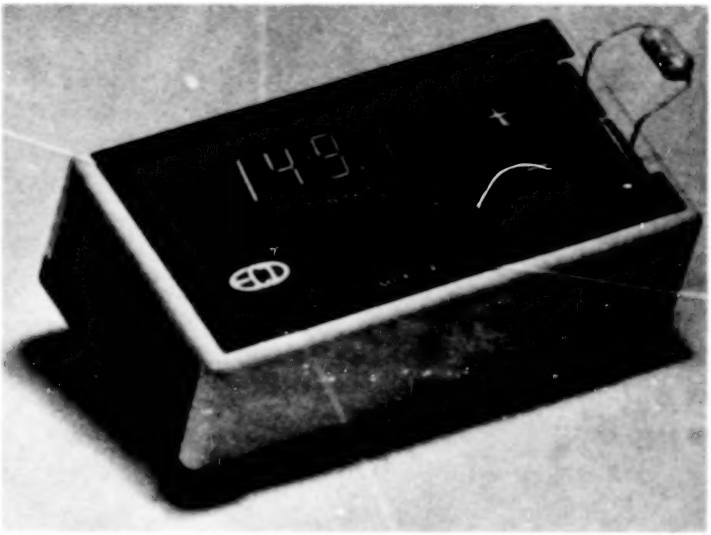


Figure 11. ECD precision autoranging digital capacitance meter.

In a similar fashion, three MIT students formed ECD Corporation in 1974 with its first product being an auto-ranging digital capacitance meter (see figure 11). While the product and its design were not developed in the Innovation Center, ECD President, Richard Eckhardt, gives much credit to the entrepreneurial courses that he took at MIT and to continued contacts with the Innovation Center. Without that help, success would have been achieved much more slowly. Annual sales volume now exceeds $200,000, the backlog is $1,500,000, and the company has expanded its product line to include a minicomputer.

Referring to table 2 that lists the Innovation Center-assisted or incubated business activities that have resulted in sales, one can see that 23 such activities exist. The circumstances by which an Innovation Center was involved with each

Table 2. Active businesses initiated or assisted by innovation centers

Business	Product	1976 Sales	1976 Order Backlog
Kemtech, Inc. (Executive Games)	TV Games	$5,000,000	$ 5,000,000
Transcomm Data Systems Corp.	Timesharing computers	2,000,000	
Compu-Guard	Security devices	1,000,000	10,000,000
Fisher Stoves, Inc.	Wood burning stove	400,000	1,000,000
Peoples Cab Co.	Transportation	250,000	
ECD Corp.	Capacitance meter	200,000	1,500,000
Three Rivers Computer Co.	Computer hardware	175,000	
Sun Publications, Inc.	Newspapers	135,000	
Transportation Concepts, Inc.	Three wheel car	117,000	2,000,000
Myers Motors, Inc.	Automobile	69,000	
Computer Controls Corp.	Control systems for HVAC	50,000	
Peoples Travel, Inc.	Transportation broker	50,000	
Rehabilitation Equipment, Inc.	Prosthetics sales and service	30,000	
MBA Consultants	Business services	20,000	
Klein Corp.	Bicycle framesets	15,000	
Richards Frames	Wood picture frame	12,000	
Wrench Knives, Inc.	Knives	12,000	
Royal Industries	Nite trainer	10,000	
Redi-Grill	Wine rack	10,000	
Vectran Corp.	Remote control devices	10,000	
Graphic Forms, Inc.	Wood printing	2,000	
SICO	Folding table	–	50,000
Health Spa, Inc.		–	250,000
Totals		$9,567,000	$19,800,000

BEST DOCUMENT AVAILABLE

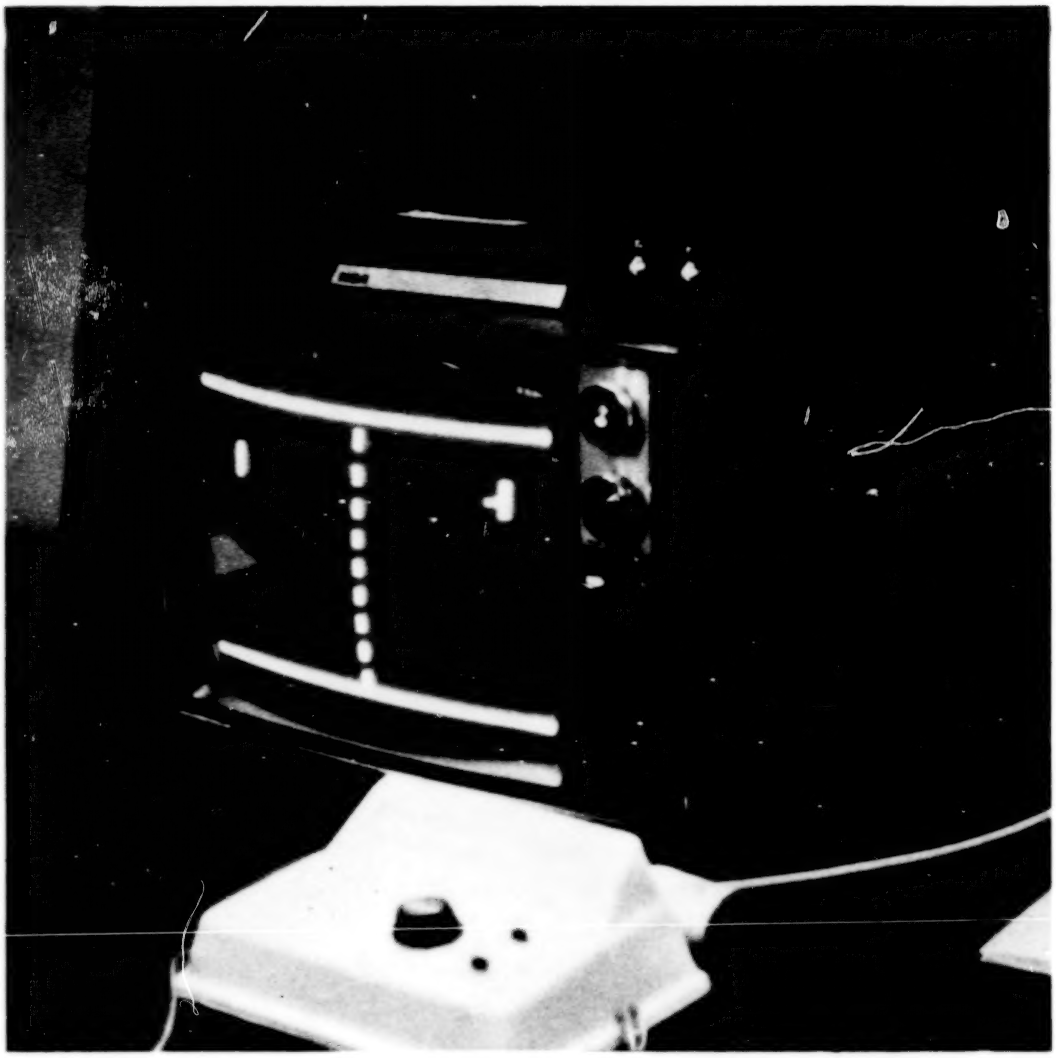


Figure 12. TV game developed in Innovation Co-op at MIT.

venture varies greatly. The first business on the list involving the TV games resulted from the Industrial Product Development Program in the Innovation Co-op at MIT (see figure 12). The product need was brought to the Center by an industrial firm, it was developed by students as part of their entrepreneurial education, and it is now a viable product.

For every business on the list, the Innovation Centers played a key role in their success. Most would not exist had that help not been available.

The total sales and backlog of these businesses in 1976 are shown in table 2. The accumulated total of sales was in excess of $30 million at the end of 1976. Employment of an unsophisticated economic model as described on the following page shows that over $6 million in direct taxes were generated by such sales. This assumes that the products do not displace other production, and does not

Calculation of Tax Generation by Innovation Center Stimulated Products

A simple tax generation model has been developed to provide a basis for developing estimates of the impact of Innovation Centers on total tax revenues.

For each dollar of sales by a manufacturing industry, an average of \$0.24 is used for employee compensation, \$0.03 for indirect business taxes, and \$0.09 is property type income (ref. 1). This is the total of the value-added in the manufacturing process. Of the employee compensation, about 13 percent is personal income taxes (ref. 2) or \$0.03 per dollar of output. While these allocations are based on older data, the proportions, which are used in the calculations, are relatively invariant with time. The tax rate for property type income is about 50 percent, so that the average total direct taxes per dollar of output in manufacturing is:

$$2.0 \times 0.105 \times \$30{,}000{,}000 = \$6{,}300{,}000$$

As indicated above, however, this represents only the *direct* generation of taxes. Since virtually all industries use the output of other industries in their production, increases in sales in one industry will increase the sales, hence taxes, in other industries. These interrelationships are captured in an input-output table. As an example, the Bureau of Economic Analysis has estimated that the household appliance industry requires a total industrial output of \$2.37 for each \$1.00 of final sales (ref. 3). This includes not only the \$1.00 of the appliance industry, but also \$0.25 for basic metals, \$0.05 for rubber, \$0.06 for electrical apparatus, etc., all except the first of which are counted at least twice but all of which generate tax revenues. Thus, for the appliance industry, it is necessary to multiply tax revenues by 2.37 in order to obtain an accurate estimate of the tax impact of increased sales. For most other manufacturing industries, this multiplier is above 2.0; so, for the Innovation Centers, a conservative multiplier of 2.0 is applied.

For \$30 million in sales, the taxes generated are therefore:

$$\text{Taxes/dollar output} = \$0.03 + \$0.03 + \$0.045 = \$0.105$$

This neglects such factors as the tax losses resulting from displacement of other domestic production by the new products, the taxes gained by the personal consumption expenditures of the workers, and other similar factors. It does, however, provide a valid and conservative measure of the tax revenues derived from the Innovation Center-associated ventures.

References:

1. Bureau of Economic Analysis, *Survey of Current Business*, April 1973, vol. 53, Washington, D.C.
2. Bureau of Economic Analysis, *The National Income and Product Accounts of the United States*, 1929-1974 Statistical Tables, August 1966, Washington, D.C.
3. Social and Economics Business Administration, *Survey of Current Business*, February 1974, vol. 54, Washington, D.C.

57

Table 3. Examples of Ideas Being Evaluated

Thermalite—a window insulation scheme for energy savings.

Music synthesizer—method for creating music by drawing waveform with hand.

Automatic tuning device—a device for indicating the musical note that is being played and how far off standard pitch that it is.

Traffic sensor—a capacitive strip sensor that gives number, speed, and weight of vehicle.

Holding tank flushing system—a device that facilitates the cleaning, disinfection, and deodorizing of holding tanks on vehicles.

Mold for utility holes—a mold to be used in constructing concrete walls to provide holes for passage of utility lines.

Clay mill—a machine for mixing potter's clay.

Mounted levels—a concept for mounting bubble levels on hand tools such as drills.

Solar panels—designed to collect solar heat and to be the southern wall of structure.

Air cleaner—a self-cleaning automotive air filter.

Disposable oxygen sensor—a sensor for measuring oxygen content of molten steel.

Mercury switch—an orientation-independent mercury switch.

account for indirect taxes resulting from personal consumption expenditures by the employees. In any case, this calculation indicates that taxes generated by Innovation Center-associated ventures exceeds the total 5-year cost to NSF of the experiment.

A number of additional ventures are in various stages of development, short of realizing sales. These include Bactex Laboratories that is concerned with the detection and prevention of gonorrhea, Hetra Corporation with a precious metal forgery detection instrument, Fab-tek, Inc., with a therapeutic knee exerciser, and Jesika with a noninvasive oximeter.

IDEA EVALUATION—A large need exists for credible evaluation of ideas and inventions. This was evidenced during the first year of the Innovation Centers Experiment when more than 500 ideas were brought to the Centers. This number has been increasing with a majority of the evaluations performed at the Oregon Center which emphasizes this function. Examples of the nature of these ideas, from all three Centers, are listed in table 3. Contacts with submitters of these ideas have established that a high level of satisfaction is being achieved, although only relatively few ideas are recommended as being worthy of continued development.

This particular aspect of the Innovation Centers Experiment has received considerable attention,* because of the need for such evaluations and the apparently inadequate service provided by commercial firms.

---

*See for example, "Whatever Happened to Independent Inventors?" ***Science News***, vol. 110, pp. 60-62, 1976; and D. Carlinsky "Inventions, The Uphill Road to Riches," ***Money***, June 1976, p. 66.

RESEARCH—There are four levels of research associated with the Innovation Centers Experiment: (1) that which comprises the experiment and its objectives, (2) that which is concerned with the organization and operational modes of each of the Centers, (3) that which deals with the invention, innovation, and entrepreneurial processes, and (4) that which is concerned with the maturation of specific ideas, inventions, innovations, or ventures. Aside from the fourth level which is a key part of center activities, the research agenda has developed slowly. At the first level, data collection instruments have been developed for evaluation of the success of the Centers in meeting their stated objectives. The substantive analysis results can only be developed in the future.[*]

The organizational or operational modes of the Centers are each different and are being continuously evaluated and adjusted to optimize performance. Relative productivity of the different modes cannot be assessed because of the variances in environment and emphasis, and because only early results are available.

Research by the Centers in the invention, innovation, and entrepreneurial process is developing. Examples of specific reports are shown (see figure 13 and appendix). The numbers of published papers (about 20), talks (about 25), and special reports (about 6) are increasing as the efforts achieve maturity. It is found that most of these research topics, and related dissertations, are derived through the business schools rather than the engineering schools.

UTILIZATION—A study of the utilization of the Innovation Centers Experiment gave it a high rating.[†] A total of 50 RANN projects were included in the utilization study, and comparisons were made among these on the basis of user responses, progress toward stated goals, and investigator opinion. In the utilization study on the Innovation Centers Experiment, 18 interviews with entrepreneurs, students, venture capitalists, government officials, industry executives, and others who have had contact with, or should know about, the Innovation Centers revealed a supportive constituency.[‡] In table 4, the factors that influenced this support are listed. *Even though the study revealed that barriers are still being encountered (e.g., lack of acceptance as full partners in the academic community, questionable financial stability beyond the period of the experiment, ventures that fail, and inventions that do not find a market), it concluded that each of the centers was in its own way demonstrating the efficacy of innovation centers in an academic environment.*

---

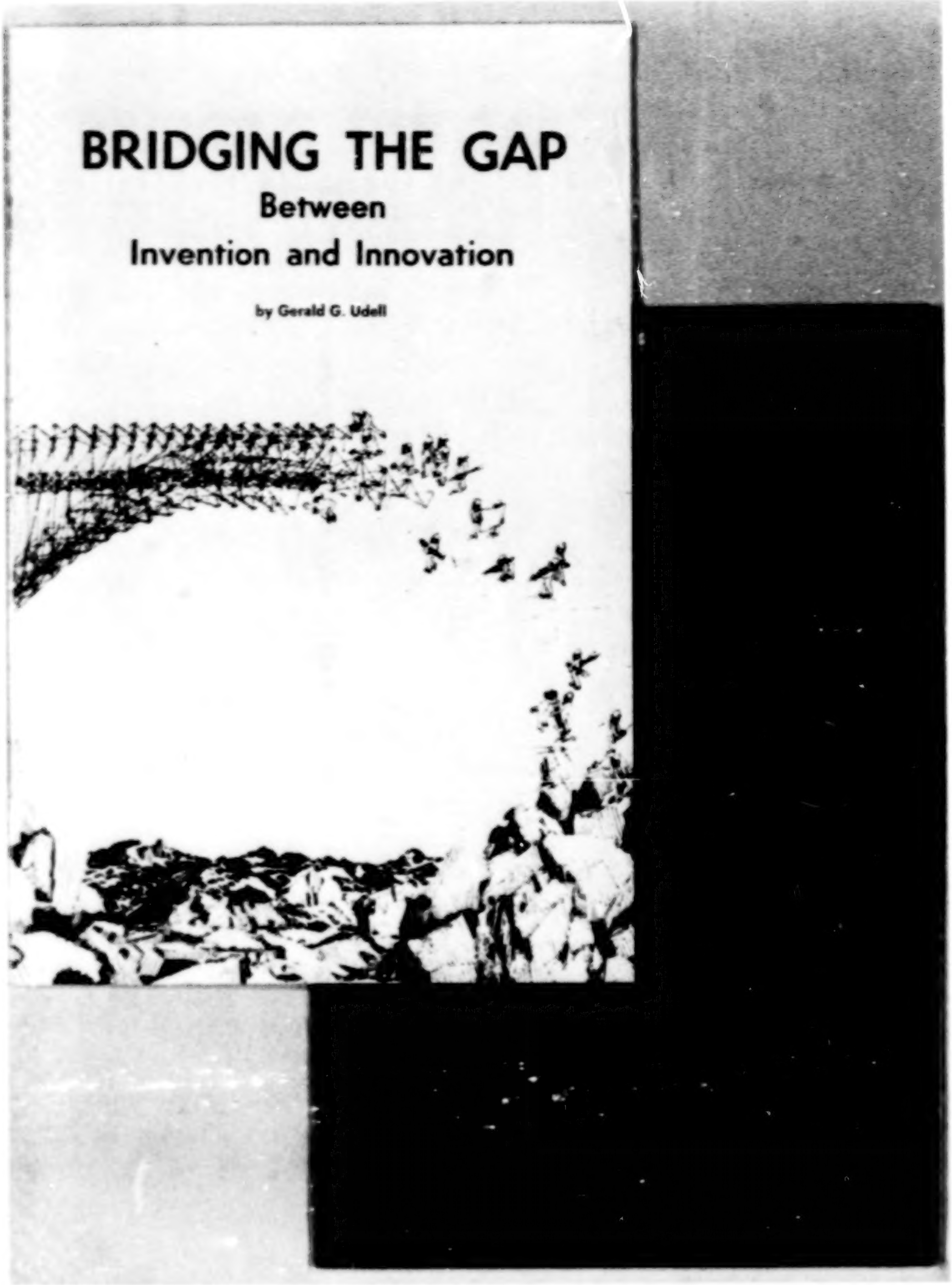
[*] R.M. Colton and G.G. Udell, "The National Science Foundation's Innovation Centers—An Experiment in Training Potential Entrepreneurs and Innovators," *J. Small Business Management*, vol. 14, pp. 11-20, 1976.

[†] R.M. Burger and M.F. Massoglia, *Utilization Analysis, RANN Research Products*, Research Triangle Institute, Research Triangle Park, N.C. 27709, May 1977.

[‡] R.M. Burger and M.F. Massoglia, *RANN Utilization Experience, Report to the National Science Foundation, Case Studies 32 through 41*, Research Triangle Institute, Research Triangle Park, N.C., November 1976.

59

BEST DOCUMENT AVAILABLE



BRIDGING THE GAP
Between
Invention and Innovation

by Gerald G. Udell

Figure 13. Research reports.

Table 4. Factors That Influence Utilization of Innovation Centers Experiment

The experimental nature of the program—emphasis is on testing hypotheses on the education of entrepreneurs and on innovation, although in each Center this is interpreted differently.

The well-defined experiment duration—knowing that NSF support of the Centers terminates in 5 years places emphasis on creation of future income and causes some to view the Centers as transient perturbations in the educational structure.

The multiobjective structure—the hierarchy of objectives creates options in approaches and products and permits commendable program flexibility. At the same time, the measures of performance are not well defined and it becomes easier to "march to the sound of the drums" rather than follow a reasoned experiment protocol.

The caliber of the directors—through selection of strong Center Directors, a strong measure of enthusiasm, competence, and zeal permeates the Centers and bodes well for their success.

The importance of the subject—innovation and entrepreneurship are in the national spotlight, thus the Innovation Centers Experiment benefits from a large receptive audience, but must bear the burden of detailed scrutiny.

The quality of the work—each of the Centers can enumerate significant accomplishment and an apparent concordance of support from those served. The early victories have aided greatly in attracting recruits to the Centers.

The resistance to change—as innovations in the education process countering established academic patterns, the Centers meet with resistance just as does any interdisciplinary program in a disciplined structure.

The block funding—the initial commitment to full funding of the programs has been important in allowing the Centers to obtain institutional status and to avoid the resource dissipation associated with renewal processes and the accompanying uncertainties.

The program management—although minor irritation was voiced relative to the documentation required for the experiment evaluation, no significant faults were attributed to NSF management in response to inquiries on this subject. All evidence points to an effective, flexible, and constructive approach to Center supervision by NSF.

The liberal patent policy—the agreements permitting the Centers to develop through patents (and other means) income that supports present and future operations, are a significant factor in the experiment design and are apparently an innovation in government policy that could have far-reaching effects.

The nature of venture capital—in the business world, venture implies levels of risks and rewards that are beyond the resources of the Innovation Centers Experiment. Thus it appears that the ventures being undertaken must be considered as small-scale laboratory experiments, and recognition must be given in the research to the factors involved in full-scale ventures.

PROGNOSIS

The Innovation Centers Experiment is still in progress. It ends in 1978. Examination of the products and effects of the experiment indicate that it is successful. The spawning of new ventures from a university base, the demonstration that entrepreneurs can be nourished in the academic environment, the development of innovative products that are suitable for production, and the development of pragmatic evaluation methods for new ideas are directly responsive to the need of universities to become more relevant to society while maintaining their traditional educational and research functions. Already, at least eight other major universities are in the process of establishing Innovation Centers based on the NSF model. Effects are spreading to the Small Business Administration where university-based small business development centers are being conceptualized for encouraging entrepreneurship. For example, committee hearings have been held in the Senate on S. 972, the Small Business Development Center Act of 1977.

Each of the Centers has established a supportive constituency; at Oregon, the independent inventor; at Carnegie-Mellon, the local business community; and at MIT, the university and participating industries. All three Centers are attracting the attention of government mission agencies for their ability to respond to specific needs.

The ultimate effect of the Innovation Centers will be to gain an enduring status as important components of major universities and through them to stimulate the regrowth of invention, innovation, and entrepreneurship in the American economic system.

> ". . . But the full panoply of engineering is innovation, including invention, the design of a new product, production of a prototype model, specification testing, market testing, the devising of new manufacturing procedures, the writing of instruction books, the selling of the product, and economic studies to insure that all of the effort is not misplaced. The ultimate test is its financial success: the production of something that people will buy.
>
> Most of our university activity, even in engineering schools, focuses on research and gives short shrift to the other elements in the innovation process. . . .
>
> Eric A. Walker
> President Emeritus, The Pennsylvania State University
>
> from "University Research—Is It Paying Off?" *Research Management*, XX, p. 7, May 1977

62

APPENDIX

ADVISORY GROUPS

MIT – Advisory Board of the Innovation Co-op

Professor A. Douglas Carmichael	MIT
Mr. Paul V. Cusick	V.P., MIT
Mr. Bernard Gordon	Pres., Analogic Corp.
Dr. Arthur Kantrowitz	Dir., Avco-Everett Research Division
Professor Francis F. Lee	MIT
Professor Yao Tzu Li	MIT, Ex-Officio
Dr. Howard McMahon	Senior V.P., Arthur D. Little
Professor Eric von Hippel	MIT
Mr. Joseph Yamron	V.P., Northrop Corp. Electronics Division

Carnegie-Mellon – CED Community Advisory Board

Leland Hazard, Chairman of the Advisory Board, Professor Emeritus of the Graduate School of Industrial Administration of Carnegie-Mellon University, and former Vice-President and Director of Pittsburgh Plate Glass Company;

Walter Blenko, a senior partner in Baskin, Boreman, Wilner, Sachs, Gondelman, and Craig law firm;

S.W. Herwald, Vice-President of Engineering, Westinghouse Electric Corporation;

Hiram Milton, President of the Regional Industrial Development Corporation;

Robert Pease, Executive Director of the Allegheny Conference on Community Development;

Robert C. Todd, Jr., Vice-President of Pittsburgh National Bank

Oregon – Western Inventors Council

John Auld
Bob Bennet
James Bjork
Floyd Dickson
Lee Eggers
John Gregor
Roger Hunt
Waldo Inman

[illegible] King
Mel Lindley
Doug McCool
Greg Page
Roger Poe III
Linda Pompel
Nancy Schoelerman
Sidney Smart

Max Wales
Robert Walker
David Whitbread
Myra Willard
Ray Willard
Patricia Williams
Walker Williams

APPENDIX

FACULTY

MIT – Innovation Education Council

Professor A. Douglas Carmichael	Ocean Engineering
Professor Ernest Cravalho	Mechanical Engineering; Associate Dean for Educational Programs, School of Engineering
Professor Woodie C. Flowers	Mechanical Engineering
Dr. Ogden H. Hammond	Chemical Engineering/Energy Lab
Professor Walter M. Hollister	Aeronautics & Astronautics
Professor David G. Jansson	Aeronautics & Astronautics/ Innovation Center
Professor Francis F. Lee	Electrical Engineering
Professor Yao Tzu Li	Aeronautics & Astronautics/ Innovation Center
Professor George C. Newton, Jr.	Electrical Engineering
Professor Eric A. von Hippel	Management
Professor David N. Wormley	Mechanical Engineering

University of Oregon

Dr. Gerald G. Udell	Director
Dr. Roman R. Andrus	Research Associate
Dr. Leslie L. D. Shaffer	Faculty Associate
Dr. Kenneth Ramsing	Faculty Researcher
Dr. Gerald Albaum	Faculty Researcher
Dr. Warren Brown	Faculty Researcher
Dr. Del Hawkins	Faculty Researcher
Dr. Paul Swadener	Faculty Researcher
Dr. Bruce Woodson	Business Development Coordinator
Dr. James Reinmuth	Acting Dean, CBA

Carnegie-Mellon University

Professor Dwight M. Baumann	Mechanical Engineer, CED
John R. Thorne	Industrial Administration
Professor Charles H. Kriebel	Industrial Administration
Professor David P. Rutenberg	Industrial Administration
Professor Arnold R. Weber	Industrial Administration Dean, Graduate School of Industrial Administration
Professor William W. Cooper	Public Policy Dean, School of Urban and Public Affairs
Professor Herbert L. Toor	Dean, Carnegie Institute of Technology

64.

APPENDIX

BIBLIOGRAPHY

(Articles which have included discussions of the Innovation Centers)

"The Breakdown of U.S. Innovation," *Business Week*, February 16, 1976, pp. 56-60.

Carinsky, D., "Inventions: The Uphill Road to Riches," *Money*, June 1976, p. 66.

Douglas, J. H., "Whatever Happened to Independent Inventors?" *Science News* **110**, July 24, 1976, pp. 60-62.

Eadens, G., "The Making of an Innovator: Getting Closer to Home," *Technology Review*, January 1975, p. 81.

Guzzardi, W., "The Uncertain Passage From College to Job," *Fortune*, January 1976, p. 126.

Holloway, C. M., "Can Students Learn To Be Inventors?" *The Chronicle of Higher Education*, March 22, 1976, p. 10.

"An Incubator for Inventions: Or How To Be an Entrepreneur While Still An MIT Student," *Technology Review*, January 1975, p. 80.

Kingsbury, L., "Innovation Centers: Turning Ideas Into Reality," *Horizons USA*, No. 19 (USIA), pp. 58-60.

APPENDIX

PUBLICATIONS

(Published articles by persons associated with centers, arranged by date of issue)

"A Call for a Philosophy of Consumer Rights," *American Marketing Association Proceedings*, August 1974.

Udell, G. G., and L. L. D. Shaffer, "An Alternative for Inventors," *Oregon Business Review* **32**, Fall 1974.

Udell, G. G. (coauthor), "An Alternative to the Internal Combustion Engine," Publishing Science Group, 1974.

Udell, G. G., "The Essential Nature of the Idea Brokerage Function," *Journal of the Patent Office Society* **57**, (October 1974), pp. 642-658.

Udell, G. G., (coauthor), "Myths and Facts About Electric Cars," *Oregon Business Review*, Spring/Summer 1975.

Udell, G. G., (coauthor), "The Electric Car: A Partial Solution to the Energy Crisis and for Geographic Areas with Temperature Inversions," *Proceedings, Western Aids*, Las Vegas, 1975.

Udell, G. G., D. McCaig, and J. Blakely, "Improving New Product Decision-Making Through Systematic Innovation Evaluation," *Proceedings, Western Aids*, Las Vegas, 1975.

Albaum, Gerald, "A Profile of Inventors," *Conference on Technology Transfer via Entrepreneurship*, sponsored by The Engineering Foundation, New England College, July 1975.

Brown, Warren, "Organizational and Information Coupling," *Academy of Management*, August 1975.

Udell, Gerald, and Robert Colton, "NSF-Funded Experimental Centers Train Innovators; Research the Innovation Process and Help Inventors," *Marketing News*, November 1975.

Udell, Gerald, and Jerald Blakely, "Toward an Improved Model for Forecasting New Product Sales," *Oregon Business Review*, Fall 1975.

Albaum, Gerald, "What Are Independent Inventors Really Like?" *Oregon Business Review*, Fall 1975.

Guerts, Michael, "Screening New Products," *Oregon Business Review*, Fall 1975.

Udell, Gerald, and Robert Colton, "The National Science Foundation's Innovation Centers—An Experiment in Training Potential Entrepreneurs and Innovators," *Journal of Small Business Management*, April 1976.

Udell, Eglington, Vigil, Sears, and Blasetti, "For the Independent Inventor, Assistance or Abuse?" *American Patent Law Association Journal*, Spring 1976.

66

APPENDIX

Udell, Gerald, and Del Hawkins, "Corporate Caution and Unsolicited New Product Ideas," *Journal of the Patent Office Society*, June 1976.

Udell, Gerald, Ken Baker, and Gerald Albaum, "Creativity, Necessary but not Sufficient," *Journal of Creative Behavior*, June 1976.

Udell, Gerald, and Robert Colton, "An Experiment in Stimulating Innovation," *Journal of the Licensing Executives Society*, June 1976.

Albaum, Gerald, and Ken Baker, "The Sampling Problem in Validation of Multiple Discriminant Analysis," *Journal of the Market Research Society*, July 1976.

Albaum, Gerald, "Selecting Specialized Creators: The Independent Inventor," *Psychological Reports*, Spring/Summer 1976.

Udell, G. G., and R. M. Colton, "An Experiment in Stimulating Innovation," *les Nouvelles II*, June 1976, p. 102.

von Hippel, E., "The Dominant Role of Users in the Scientific Instrument Innovation Process," *Research Policy* **5** (1976), pp. 212-239.

von Hippel, E., "The Dominant Role of the User in Semiconductor and Electronic Subassembly Process Innovation," *IEEE Transactions on Engineering Management EM-24*, May 1977, pp. 60-71.

Udell, Gerald, "Outside Submittals: A Macro Point of View" (see "Unsolicited Product Ideas—A new Evaluation Program"), *Research Management*, July 1976.

Ramsing, Ken, and Gerald Udell, "Franchising: The Carrot or the Stick?" *Australian Franchise Review*, (to be published).

Udell, G. G., "The Calf Path In Franchising," accepted by the *Law Institute Journal* (Australia).

Udell, G. G., (coauthor), "Marketing Technologically New Products," - accepted by the *Journal of the Academy of Marketing Sciences*.

Udell, G. G., "Can Academia Really Reach Out?" accepted by the *Journal of Extension*.

Udell, G. G., "The Role of Evaluation in Monitoring and Improving Change Agent Effectiveness and Efficiency," accepted by the *Journal of Extension*.

APPENDIX

PAMPHLETS AND REPORTS

Center for Entrepreneurial Development, Carnegie-Mellon University

Operating Plan, September 1974.
First Annual Report, September 1974.
Second Annual Report, September 1975.
Third Annual Report, October 1976.
Ten Readiness Steps.
How to Start Your Own Business.
Most Frequently Asked Questions About the Center.
All About CED.

Oregon Innovation Center

Center Mission and Second Annual Report, June 30, 1975, September 1975.
Third Annual Report, September 1976.
Explorations Series:
- "A Breeding Ground for Entrepreneurs and Innovators," by G. G. Udell.
- II "The Coupling Problem in Technological Innovation," by Warren Brown, Spring 1976.
- III "The Independent Inventor," by Gerald Albaum, Spring 1976.
- IV "A Guide to Venture Capital by Paul Swadener, Spring 1976.
- V "Corporate Policy and Unsolicited New Product Ideas." by Del Hawkins, Spring 1976.

"Bridging the Gap Between Invention and Innovation," "The Essential Nature of the Idea Brokerage Function," by G. G. Udell. ' Guide to Invention and Innovation Evaluation," 1977.

MIT Innovation Center

MIT Innovation Center.
MIT Innovation Center Annual Program Description, July 1, 1975-June 30, 1976, August 1976.
"Development of Future Innovators and Entrepreneurs," by Y. T. Li, December 1975.
"Introduction to Teaching Invention," Y. T. Li, January 1976.

☆U.S. GOVERNMENT PRINTING OFFICE: 1979 O—625-774/1405 REGION 3-1

68

SECTION III.

An Analysis of the National Science Foundation's University-Industry Cooperative Research Centers Experiment

BEST DOCUMENT AVAILABLE

This description of the University-Industry Cooperative Research Centers Experiment was prepared by the Research Triangle Institute for the National Science Foundation. R. M. Burger is the author; S. H. Cole and C. H. Burnett, Jr., contributed to both the content and the form of this analysis. The content is based on reports and other material provided by the directors of the three centers and by R. M. Colton, the NSF Program Manager, and on interviews with persons who have had contact with, or knowledge of, the centers. Mr. Colton has, in addition, reviewed this report and concurs as to the authenticity of the data. Any opinions, findings, and conclusions or recommendations are those of the author and do not necessarily reflect the views of the National Science Foundation or of the Cooperative Research Centers.

Research Triangle Institute
P. O. Box 12194
Research Triangle Park,
North Carolina 27709

BEST DOCUMENT AVAILABLE

An Analysis of the NATIONAL SCIENCE FOUNDATION'S UNIVERSITY-INDUSTRY COOPERATIVE RESEARCH CENTERS EXPERIMENT

an effort to stimulate
university-industry
cooperative research
in solving R&D problems
in American industry

71

PREFACE

The University-Industry Cooperative Research Centers Experiment is part of a continuing effort by the Federal Government to test and evaluate unique institutional arrangements for stimulating technological progress in the private sector. The suitability of replicating these institutions as a public policy is judged by a number of criteria including: importance of the problem being addressed and the leverage and effectiveness of the solution posed; the costs, legal aspects, equity, understanding, acceptance, and administration of the policy for replicating the institution; and the hypothesis, design, and feasibility of the experiment used to develop and evaluate the institution.

As the experiment is reaching its end, it has shown a great measure of success both from a performance standpoint and in satisfying the posed criteria.

The data included in this report substantiates this conclusion. It is anticipated that data collected in the future will continue to show that University-Industry Cooperative Research Centers are a suitable institutional arrangement on which to base a national policy.

R. M. Colton
January 1979

SUMMARY

> "If the United States is to meet foreign competition and if its industries are to provide jobs for American workers, I am convinced that there must be closer cooperation between academic and industrial researchers."
>
> Statement of Dr. Richard C. Atkinson, Director of the National Science Foundation, before the Subcommittee on Science, Research, and Technology, Committee on Science and Technology, U.S. House of Representatives, January 24, 1978.

The above statement provides the rationale for a 5-year experiment in which $2,400,000 in National Science Foundation (NSF) funding and an estimated $3,000,000 of industry funds have been invested. The experiment consists of three university-industry cooperative research centers, each directed to working on R&D problems of a specific American industry. This report describes the experiment and its results.

The objective of the University-Industry Cooperative Research Centers Experiment was to determine if Federal cost-sharing during a 5-year period would enable the creation of industry-funded permanent cooperative research centers. The centers were operated by North Carolina State University (NCSU), Massachusetts Institute of Technology (MIT), and the Mitre Corporation and addressed R&D needs of the furniture industry, the polymer processing industry, and energy-related industries, respectively. Operational approaches of each of the centers differed, but the objectives, schedule, and incentive structure were common. Participating firms obtained special benefits from participation, and they can protect proprietary interests and share in patent rights ensuing from the research.

Twenty-four commercial firms have provided direct funding to center operations while a much greater number have shared in the funding of center activities and have participated in center projects. Sixteen universities have been involved in the projects of the three centers. Although a variety of publications, patents, procedures, processes, and products have been produced, the length of the normal application cycle inhibits meaningful evaluation of these at

73

this time. In the judgment of many of the industry sponsors, however, the value of the centers has been proven.

The ultimate measure of success is achievement of the prime objective: sufficient industry support to permit continuation beyond the period of NSF support. For one of the centers, this is assured. The Polymer Processing Program at MIT is continuing with solid industry support that exceeds the early expectations. The Furniture R&D Applications Institute at NCSU is being forced to retrench with termination of the experiment but may obtain continuity in modified form. The New England Energy Development Systems (NEEDS) Center, which was operated with the Mitre Corporation providing the university-industry interface, has identified weaknesses associated with this intermediary form of center operation and will cease its operations. However, some activities that the NEEDS Center has spawned may continue as cooperative programs. These results indicate that the amount of government cost-sharing required for continuation after the initial startup period varies with the nature of the industry, ranging from none, as for the polymer processing industry, to 50 percent or greater for industries with less of a research tradition or for which the technological content of the product is less important.

The results of this experiment indicate conclusively that university-industry cooperative research is a viable concept. Dr. Atkinson's statement to the congressional committee (see box) states a need for which this University-Industry Cooperative Research Centers Experiment has demonstrated one method of fulfillment. Industry will fund such cooperation and believes the results are applicable to its needs. University faculty has found industry research to be challenging and within the purview of the academic environment. Finally, although the proof is not yet available, it appears that the fruits of cooperative research will acrue to the benefit of American industry and American workers.

TABLE OF CONTENTS

SUMMARY
v

INTRODUCTION
1

CONCEPTION
4

CENTERS
7

COMPOSITE
27

CONCLUSIONS
31

15

INTRODUCTION

Historically, American industry has been characterized as highly technological, innovative, and aggressive. Whether or not this is true today is the subject of considerable discussion and concern. Consider the following typical problems:

- Two 400-megawatt generating units of a large utility were designed to operate satisfactorily in the range of 102 to 400 megawatts in response to variations in the utility's load. However, instabilities in the control systems for these units have prevented their operation below 220 megawatts. This was a problem that had not been solved by conventional approaches and that had a long history of occurrences.
- Furniture manufacturers utilize lumber storing and handling procedures that were developed when hardwood was relatively inexpensive. Losses in open storage, drying, and handling are contributing to rapid cost escalations in the industry. The competitive erosion of this American industry is foreseen unless technology is brought to bear on such problems.
- Mixing of powders and liquids in the polymer processing industry has lacked a scientific basis. Poor mixing, excessive costs, and product limitations have resulted. Few, if any, technological advances have been made in the last decade.

Each of these problems is associated with a major U.S. industry and has important economic ramifications. In 1973, little effort was being expended toward their solution—the highly technological, innovative, and aggressive characteristics of American industry were being exhibited in other industries perhaps, but certainly not in these three. Reasons for this lack of applied research were given—tradition, fragmented industry, proprietary technology, regulatory climate, etc.—but these reasons did not provide solutions to the problems.

Researchers associated with the New England Energy Development Systems (NEEDS) Center have now solved the generator instability problem; the Furniture R&D Applications Institute has introduced lumber handling and storage concepts that, for some furniture manufacturers, have had significant impact on their yields; and the Polymer Processing Laboratory has not only developed a scientific basis for mixing but has advanced the relevant technology on several fronts. The NEEDS Center, Furniture R&D Applications Institute, and Polymer Processing Laboratory are the three major components of the National Science Foundation's University-Industry Cooperative Research Centers Experiment.

Academic research in the United States has a rich tradition and is a key partner in technological progress in many areas—computers, control systems, medicine, natural resources, agriculture, and others. The expansion of academic research in the post-World War II era was based upon strong Federal support.

76

BEST DOCUMENT AVAILABLE

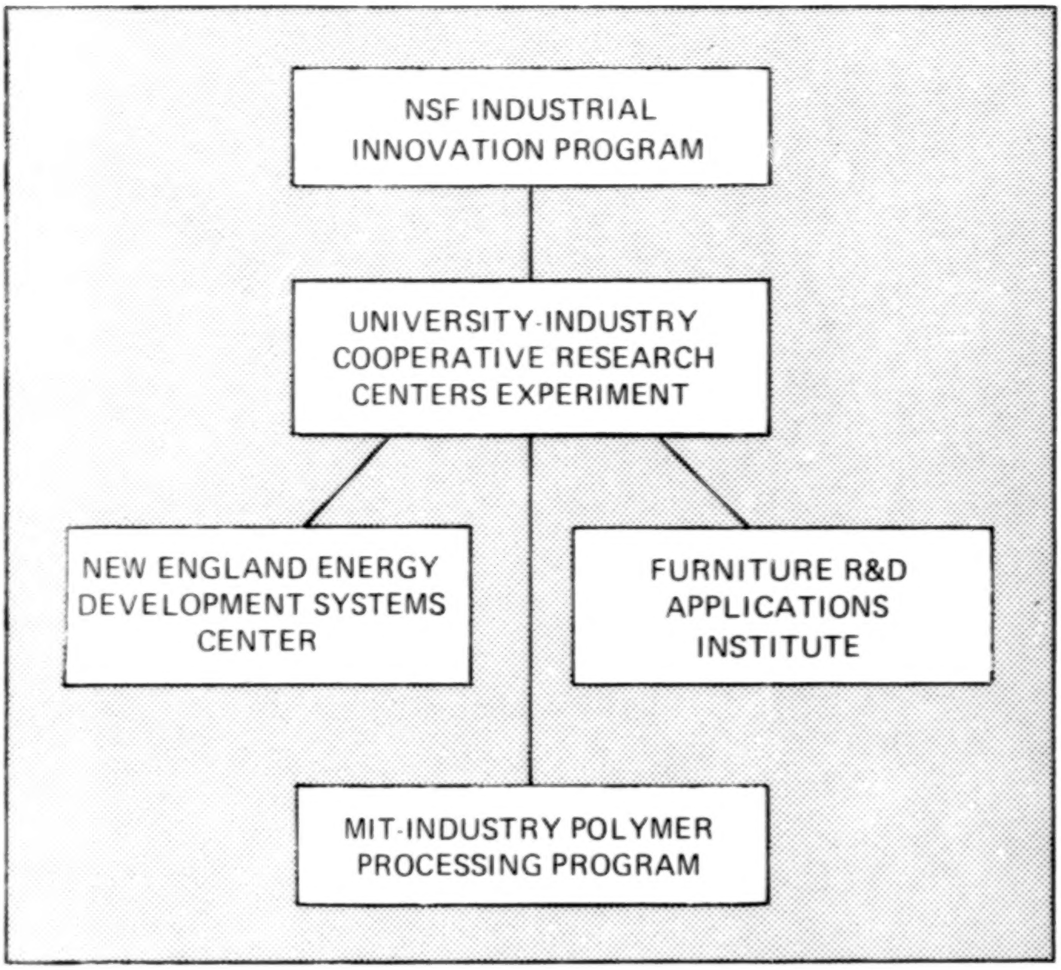

NSF INDUSTRIAL INNOVATION PROGRAM
UNIVERSITY-INDUSTRY COOPERATIVE RESEARCH CENTERS EXPERIMENT
NEW ENGLAND ENERGY DEVELOPMENT SYSTEMS CENTER
FURNITURE R&D APPLICATIONS INSTITUTE
MIT-INDUSTRY POLYMER PROCESSING PROGRAM

Figure 1. Structure of the University-Industry Cooperative Research Centers Experiment.

The role of the universities was recognized by key Government officials who fostered ONR, NSF, AFOSR, ARO, NIH, NASA,* and other agencies that directed funding to universities to support research in a variety of areas. This resulted in rapid growth of academic research activities. However, in the 1970's, with the impact of inflation and the establishment of new pressures on government spending, Federal support for research began to diminish. If academic research was to maintain its strength, alternative funding mechanisms were needed. A natural solution was to revamp academic research to put it more in harmony with the needs of industry, thereby attracting industry support.

---

*ONR, Office of Naval Research; NSF, National Science Foundation; AFOSR, Air Force Office of Scientific Research; ARO, Army Research Office; NIH, National Institutes of Health; NASA, National Aeronautics and Space Administration.

NSF, recognizing industry requirements for applied research support and the decreasing level of Federal support for academic research, formulated the University-Industry Research Centers Experiment as one part of the Industrial Innovation Program (see figure 1). The result is that university researchers have either solved or made important contributions to the solution of problems such as the examples given. Moreover, the viability of such university-industry cooperative research programs has been demonstrated and conditions identified for replication of this success. The experiment has identified a method that can serve to bring universities and industry into closer ties with one another, resulting in important mutual benefits.

This report describes and analyzes the University-Industry Cooperative Research Centers Experiment so that its findings may be disseminated and applied. If the result is an expanded scope of university-industry cooperation in research, then the experiment will have achieved its ultimate goal.

Research Management, September 1978

THE DECLINE IN INDUSTRIAL RESEARCH – CAUSES AND CURES
by G. E. Manners, Jr., and H. K. Nason

"... As recently as 1958, industry was responsible for over 60% of all research performed in this country ...; this percentage contribution has consistently declined to a level of 40% in 1976. ... In 1958, industry allocated as much as 38% of its R&D dollar to 'R'. The percentage has decreased year after year – reaching a minimum of 25% in 1976."

CONCEPTION

"To determine effective ways of stimulating non-Federal investment in research and development and of improving the application of research and development results"* was the charge given to the National Science Foundation (NSF) and the National Bureau of Standards (NBS) by the President in 1972. The Research and Development Incentives (RDI) program or, as it is now called, the Industrial Innovation Program (IIP) was one NSF response. The other response from NSF was the R&D Assessment Program. From NBS, it was the Experimental Technological Incentives Program. IIP is structured as an experimental program because it is not clear which of the many ways that the Government can intervene in civilian R&D will be most effective. In its first 2 years, IIPinitiated 10 experiments, one of which is the Cooperative Research and Development Experiment, or as it is now called, the University-Industry Cooperative Research Centers Experiment. The complete IIP program content is shown in table 1.

The University-Industry Cooperative Research Centers Experiment is designed to explore the feasibility of linking university R&D resources with industy's needs. The objective is to move technology into the marketplace more rapidly. The experiment is based upon the hypothesis that the rate of technological innovation in many traditional industries can be increased by cooperative arrangements between schools of engineering and companies in these industries. The mechanism is perceived as cooperative research programs stimulated by Federal cost-sharing of limited duration and by allowing negotiation of rights to patents ensuing from the research. The barriers to cooperative R&D are believed to consist of:

- *cost*—particularly for small companies that operate on low profit margins,
- *patent rights*—the practice of the Federal Government to retain patent rights to Government-financed inventions,
- *publications*—the conflict between the right of university researchers to publish and the proprietary interests of industrial firms,
- *utility of university research*—the perception by industry that university research is of little direct value to industry,
- *approach*—the apparent mismatch between the discipline-organized university and the mission orientation of industry.

The challenge of the experiment is to find mechanisms for removing these barriers, and other barriers that might be identified in the course of the research. Finally, the broad applicability and implications of these mechanisms are to be assessed.

The University-Industry Cooperative Research Centers Experiment was initiated in 1972 with a program announcement soliciting proposals. In June of

---

*President's message to the Congress on Science and Technology, March 16, 1972.

Table 1. Industrial Innovation Program

PUBLIC SECTOR

- Experimental Urban Technology System
- Increasing Use of Technology in Local Government Units in Oklahoma
- Stimulating Technology Applications and Utilization in Smaller Units of Local Government
- Experimental Legislative Office of Technical Asssistance
- Experimental Federal-State Technology Transfer Mechanism
- Regional Approach to the Transfer of Technology

PRIVATE SECTOR

- Federal Laboratory Validation
- Medical Instrumentation
- Cooperative Research Centers
- Innovation Centers

Table 2. Participants in Phase 1 of the University-Industry Cooperative Research Centers Experiment

Program Area	Organization
Furniture R&D applications	North Carolina State University
Polymer processing	Massachusetts Institute of Technology
Energy systems	Mitre Corporation
Construction industry	American Society of Civil Engineers
Laser and electrooptical applications	Case-Western Reserve University
Crushed stone industry	Martin Marietta Corporation
Nondestructive testing applications	University of Connecticut
Needle trades industry	University of Massachusetts
Fisheries and mariculture industry	University of Rhode Island
Biomedical instrumentation industry	University of Southern California
Private telephone systems manufacturers	Virginia Polytechnic Institute
Cooling towers industry	Washington University
Biomedical center for analysis of radiographs	Wright State University
Materials sciences applications	University of Connecticut

80

1973, 14 organizations were funded for an initial phase in which the model of the cooperative effort would be defined, commitments would be obtained from industry, agreements for collecting data on the experiment would be obtained, and allocation of patent rights would be determined. NSF had previously agreed that Government patent rights would be assigned to the participating organizations. The 14 programs are listed in table 2. Only three were funded for the 4 year operational phase that followed. These are described in the following section.

In order to meet the assessment objectives of the experiment, an evaluation effort has been funded at Denver Research Institute. In this effort, the overall experiment design is structured, the components of the experiment are integrated, and outputs of the experiment are monitored and summarized.

The ultimate success of the University-Industry Cooperative Research Centers Experiment is to be based on the following expected results:

- An increase in the amount of non-Federal dollars invested in R&D,
- More effective utilization of university and R&D institute resources,
- Changed attitudes on the part of industry toward the value of R&D,
- Changed university attitudes toward being involved in industry problems,
- Efficient and effective transfer of technology from R&D into applications in industry,
- Increased effectiveness and/or productivity of R&D,
- Increased knowledge of R&D barriers and incentives, and adjustments in public policy accordingly.

More immediate measures of success are:

- Industry direct financial and other support for the center that is adequate to insure continued viability,
- Faculty and student participation in R&D for industry,
- Active industry involvement in center activities,
- Acceptance by universities of their role in industry-oriented R&D.

CENTERS

The three centers that comprise the University-Industry Cooperative Research Centers Experiment are located at North Carolina State University (NCSU), the Mitre Corporation, and Massachusetts Institute of Technology (MIT). These are described briefly in table 3 and more completely in the following paragraphs. The salient features of this triad include these:

- At NCSU and MIT, the university-industry linkage is direct; Mitre, however, serves as a broker between the two parties;
- Government funding is in the approximate ratio of 2:3:5 for MIT: NCSU:Mitre, respectively;
- In only one case (at MIT) was the center director to be a university faculty member;
- MIT's program content was oriented to basic and applied laboratory investigations while those of the other two centers ranged from applied laboratory investigations to operational and policy matters;
- Student participation was the key feature at the MIT center, was at a low level for the Mitre center, and was almost nonexistent at NCSU;
- Each of the centers had a specified target for industry support that was scheduled to increase rapidly during the period of the experiment.

The three centers are more different in their approach to cooperative research than is apparent from the above list. MIT saw its strengths in the products of its laboratory research and in the strong technical communication linkages that would be established with a small group of industry sponsors. Mitre began with a strong technical participation in a utility problem but found it necessary to broaden into an opportunistic response pattern with strengths in program development and management in order to address the overall program objectives. At NCSU, the center operations were treated as an extension service having R&D in several technical areas but with emphasis on relatively low technology operational problems. This diversity in approaches necessarily results in a diversity in results and creates a problem in abstracting overall program findings.

FURNITURE R&D APPLICATIONS INSTITUTE

The furniture industry has characteristics that make it a good target for a cooperative research center program. It is highly fragmented, carries out little research on its own, is labor intensive, and is therefore vulnerable to changing conditions. One-third of the industry is concentrated in North Carolina and comprises over 500 plants and over 60,000 employees. North Carolina State University (NCSU) has an excellent association with the furniture industry. It offers an industry-supported undergraduate program in furniture

82

manufacturing and management, the only one of its kind in the United States, and its faculty actively participates in industry affairs. Thus it is not surprising that the proposal submitted by NCSU in response to the NSF program announcement for the University-Industry Cooperative Research Centers Experiment was considered favorably. The NCSU proposal was the only one of the 200 preliminary proposals and 70 final proposals that was funded for the full 5 years of the experiment. Other submissions (13) were given program definition grants of up to one year.

Although the Furniture R&D Applications Institute is not a success – the level of industry support required for its continuation in its present form has not been obtained – everyone associated with the program believes that the original concept is still valid. If this is true, then either the circumstances during the ex-

Table 3. University-Industry Cooperative Research Centers

Furniture R&D Applications Institute
North Carolina State University
Raleigh, North Carolina

Director: A. L. Prak 7/73 to 7/75
J. J. Markel 8/75-7/76
H. Burton 8/76-9/78
J. Ekwall 9/78-present

Period: July 1, 1973 – September 30, 1978
NSF Funding: $708,000
Objective: To test the feasibility of stimulating a lasting and mutually profitable university-industry R&D relationship in an important fragmented crafts industry, the furniture industry.

New England Energy Development Systems (NEEDS) Center
Mitre Corporation
Bedford, Massachusetts

Director: P. R. Vance 6/73-7/78
Zwi Kohorn 7/78-present

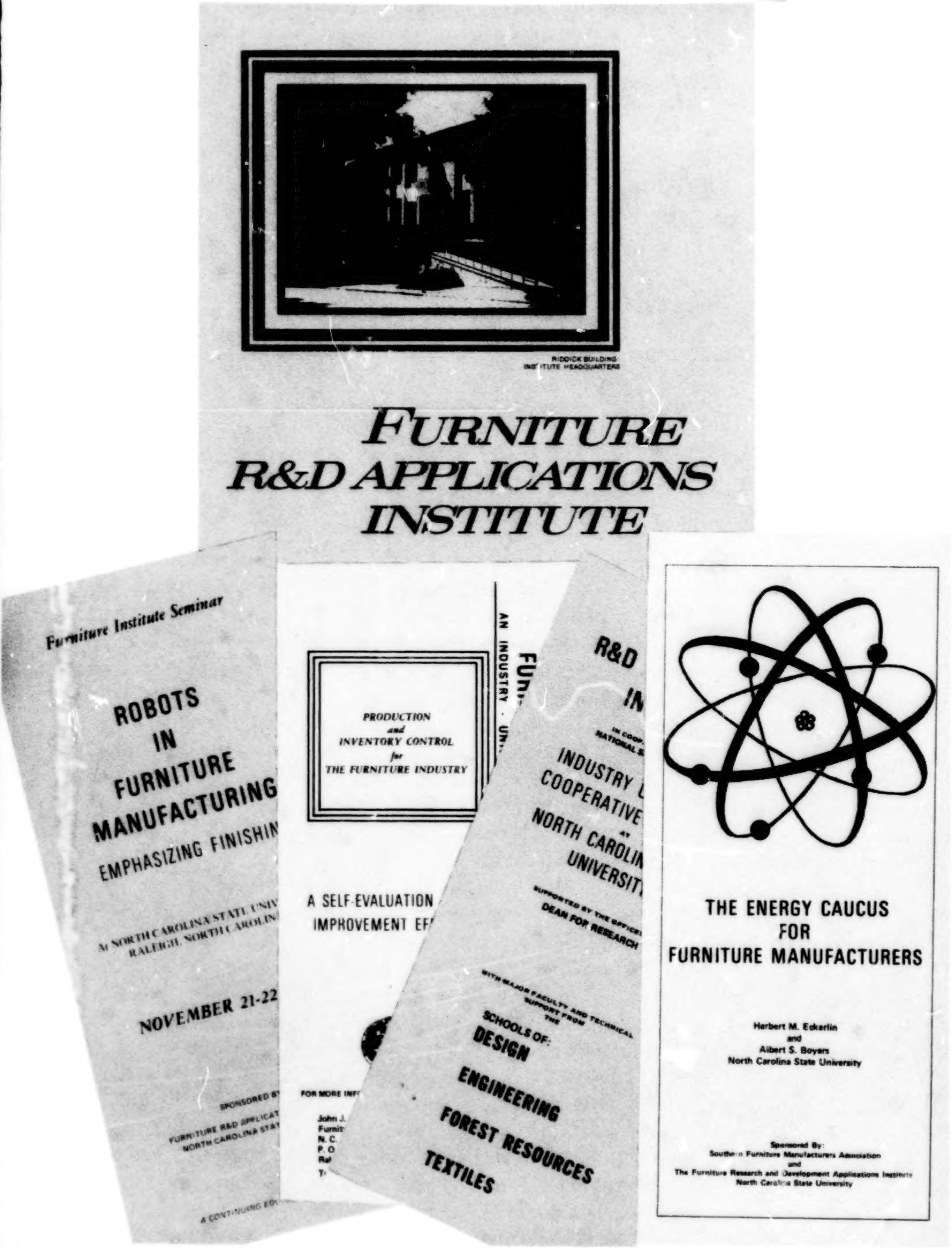
Period: July 1, 1973 – June 30, 1978
NSF Funding: $1,274,000
Objective: To test the feasibility of a lasting and mutually beneficial relationship between the university research community and traditional energy-related industry catalyzed by a nonprofit institution.

MIT Polymer Processing Program
Massachusetts Institute of Technology
Cambridge, Massachusetts

Director: N. P. Suh 6/73-present

Period: July 1, 1973 – June 30, 1978
NSF Funding: $469,000
Objective: To establish an industry-sponsored and self-sustaining program to serve the long-range R&D needs of the plastic processing industry and to determine if such a relationship between a university and industry can facilitate the development, adaptation, and adoption of new technology.

BEST DOCUMENT AVAILABLE



RIDDICK BUILDING:
INSTITUTE HEADQUARTERS

FURNITURE
R&D APPLICATIONS
INSTITUTE

Furniture Institute Seminar

ROBOTS
IN
FURNITURE
MANUFACTURING
EMPHASIZING FINISHIN

At NORTH CAROLINA STATE UNIV
RALEIGH, NORTH CAROLIN

NOVEMBER 21-22

SPONSORED BY
FURNITURE R&D APPLICAT
NORTH CAROLINA STAT

A CONTINUING EDU

PRODUCTION
and
INVENTORY CONTROL
for
THE FURNITURE INDUSTRY

A SELF-EVALUATION
IMPROVEMENT EF

FOR MORE INF

John J.
Furnit
N. C.
P. O
Ral
T

FUR
AN INDUSTRY · UN

R&D
IN
IN COOP
NATIONAL S
INDUSTRY U
COOPERATIVE
AT
NORTH CAROLIN
UNIVERSIT
SUPPORTED BY THE OFFICE
DEAN FOR RESEARCH

WITH MAJOR FACULTY AND TECHNICAL
SUPPORT FROM
THE
SCHOOLS OF:
DESIGN
ENGINEERING
FOREST RESOURCES
TEXTILES

THE ENERGY CAUCUS
FOR
FURNITURE MANUFACTURERS

Herbert M. Eckerlin
and
Albert S. Boyers
North Carolina State University

Sponsored By:
Southern Furniture Manufacturers Association
and
The Furniture Research and Development Applications Institute
North Carolina State University

Figure 2. Activities of the Furniture R&D Applications Institute.

Table 4. Industry Sponsors of the Furniture Institute

Amstore, Inc.	Muskegon, Michigan
Athens Home Decor	Athens, Tennessee
Bernhardt Industries	Lenoir, North Carolina
Burlington House Furniture	Lexington, North Carolina
Burris Industries, Inc.	Lincolnton, North Carolina
Forest Products, Inc.	Morristown, Tennessee
Fox Manufacturing Company	Rome, Georgia
Stanley Furniture	Stanleytown, Virginia

periment phase were unfavorable or the period was inadequate for accomplishment of the objectives. A combination of both is probably the correct answer. In order to understand this, however, one must examine the organization and program of the Institute. (See figure 2 and tables 4, 5, and 6.)

The cooperative agreement establishing the Furniture R&D Applications Institute was effected on July 1, 1973, and provided $708,700 in NSF funds for the period of NSF support terminating September 30, 1978. The targeted support from industry was $561,190 and was expected to increase over the life of the program so that about 50 percent of the total from industry would be obtained in the final year and would continue at that rate beyond the period of NSF support. Correspondingly, the NSF support would be low – 11 percent of the total award, in the last year. The cooperative agreement provided the University with considerable latitude in the manner by which the Institute would be operated, requiring only that Institute plans, charter, and other relevant documentation be submitted for approval by NSF and providing for a full review of the Institute 2 years after its initiation.

It is necessary to note that the Institute was not established in an area barren of technology. Over a year before the Institute was founded, the Clark Chair frame had been invented (see figure 3) and was to provide one of the continuing thrust areas for the Institute, computer aids for cutting lumber had been developed and promoted, and the Industrial Extension Service of the University had been conducting in-plant workshops. Three university departments had participated in furniture industry activities: Industrial Engineering from the School of Engineering, and both the Wood and Paper Science Department and the Forestry Department of the School of Forest Resources.

The proposal for the Furniture Institute was a joint effort of four faculty members – Anco Prak and John Canada from Industrial Engineering and Aldos Barefoot and Irving Goldstein of Wood and Paper Science. It provided for the Institute to operate with a strong director reporting to a Board of Directors chaired by the Dean of Research and consisting of Deans of the involved schools of the University. This Board would, in turn, be assisted by an Advisory Board consisting of appointed representatives of sponsoring companies. The research agenda of the Institute was to be based primarily on needs perceived by industry spon-

85

Table 5. Projects of the Furniture Institute

CLARK UPHOLSTERY FRAME—The Clark frame is a bridge-frame construction design for curved upholstered chairs characterized by greater design flexibility, reduced weight, lower costs, greater strength, and more predictable performance than for traditional frames. It was originally developed by E. L. Clark at North Carolina State University before the Furniture Institute began. Institute effort has been in development of manufacturing methods and materials, promoting adoption of the frame by furniture manufacturers, and technology transfer to industry. The culmination of this effort has been the formation of a company that will make and sell the chair frames. This follows several unsuccessful attempts to have the frame adopted by an existing furniture company.

FINGER JOINTING—This is an old technique for joining wood that has the potential for reducing costs and increasing efficiency of wood usage, but had not been applied in the furniture industry. The Wood Products Laboratory at NCSU, under an Institute project, investigated finger jointing technology and demonstrated a number of applications. The economics of finger jointing was also analyzed and cooperative experiments undertaken with furniture companies. The finger jointing technology is being gradually adopted by the furniture industry.

LUMBER YIELD IMPROVEMENT—According to the Furniture Institute, some $50,000 in investment and as much as 1,500 executive hours have been expended in the furniture industry to improve its methods of lumber handling, leading to savings conservatively estimated at several million dollars. This has resulted directly from Institute analyses of losses associated with lumber handling. Major barriers persist in the introduction of improved methods primarily due to a reluctance to change from the traditional practices which are known to work.

MECHANIZATION IN FINISHING—This project was oriented to eliminating or minimizing the hand labor involved in furniture finishing. The operation most amenable to mechanization is the wiping operation in which excess stain or glaze is removed. After investigation of several approaches, a vacuum brush was designed for the wiping operation and field tested in a furniture factory. Results are encouraging and the pathway to eventual automation of the wiping operation is being defined.

MATERIALS HANDLING—This Institute project entailed a broad study of materials handling in the furniture industry. It revealed opportunities for contributions that were met by subprojects on high rise warehousing, handling of veneer flitches, and evaluation of materials handling alternatives.

MOISTURE CYCLING IN DOWEL JOINTS—This project was aimed at determining the effects of adhesive thickness and internal slotting on dowel joint integrity. It was carried out at the University of Massachusetts and was motivated by an important problem with dowel joint failure in furniture.

LUMBER DRYING—This is an interactive project with the industry and involves a general analysis of existing practices, the determination of operational parameters, and an evaluation of the potential for improvements. The lumber drying project is closely associated with the lumber yield project and has the same general results; i.e., it was determined that the cost savings potential is large but that the barriers to achieving these savings are nontechnical.

UPHOLSTERY FRAMES—This project is an outgrowth of the Clark frame and seeks to extend that technology to other furniture operations and to expand on it with other technological innovations. This project has not produced significant results to date since it is relatively new.

MISCELLANEOUS—A number of other projects have been undertaken at various levels of effort and with varying levels of success. These include the following:

- **MOULDER STUDIES**—Moulders are widely used in furniture manufacturing to provide decorative finishes. The initial step of this project was to classify rejects from the moulder operation by source.
- **QUALITY CONTROL**—In the furniture industry, formal quality control procedures are rarely used. This project was directed toward identifying existing procedures and assemblying procedures which are applicable to the industry.
- **BENT PLYWOOD JOINT REINFORCEMENT**—The technology has been patented and tested by a manufacturer. The design is used to strengthen chairs and other furniture items and is patented under the name Plymate.
- **CARVE-EMBOSS PROCESS**—This project involves study of the process by which complex decorative patterns are formed in wood with the objective of reducing the time required to form them and improving the quality of the products.
- **WORKSHOPS**—As a continuation of the university's extension service to industry, workshops on production control and inventory were developed and presented at a number of companies.

BEST DOCUMENT AVAILABLE

Table 6. Summary Analysis of Furniture R&D Applications Institute Activities, 1973-1977

PROJECTS			PROJECT ACTIVITIES											INDUSTRY RESULTS		
Project Name	Years Funded	Institute Expenditures	Research	Extension	Idea Generation	Publications	Patents	New Products	New Process	New Applications	Process Controls	Faculty/Staff Involvement	Student Involvement	Industry Applications	Industry Expenditures	Industry Benefits
Clark Frame	73-76	$ 63,277	●		●	●	●	●	●			3	●	1 Licensee 2 Prospects	$ 20,000	19-24 Frame Cost
Production & Inventory Control Workshop	73-74	15,281		●		●					●	2	●	6 in Company Workshops	50,000-70,000	Yes?
Finger Jointing	73-75	13,803	●		●	●				●		2	●	Involved in Installing 3 Systems	40,000-60,000	Yes?
Lumber Yield & Drying Improvements	74-77	**169,283**	●	●	●	●				●	●	4	●	22 Companies Part.	698,000-748,000	$1,471,000-2,051,000 Annual
Robots in Finishing	74-76	40,663	●		●				●			3	●	Experimental Trials in 3 Companies	8,000	Potential
Equipment File	74	3,000		●								1	●	---	---	?
Materials Handling	75-77	52,469	●	●	●	●				●	●	3	●	7 Companies Part. 20 Companies Att. Workshops	10,000	Yes?
Workshops	75-77	4,000		●		●			●	●	●	7	●	---	4,000	Yes?
Moisture Cycling of Dowel Joints	75	9,700	●		●	●			●			1	●	Experimental Trials in 1 Company	1,000	?
Upholstered Frame Innovations	76	3,768	●	●	●				●	●		2	●	3 Companies Part.	3,000	.20-.70 Frame
Molder Yield Study	76	1,205	●			●					●	2	●	2 Companies Part.	2,000	Yes?
Q.C. Procedures Manual	76-77	14,461	●		●	●				●	●	2	●	3 Companies Part.	Yes?	Yes?
Plymate Joint Reinforcement	76	5,765	●		●	●	●	●		●		2	●	Experimental Trials in 4 Companies	1,500	?
Carve-Emboss	76	2,000	●	●	●	●			●	●		2	●	Production in 4 Companies	230,000	Improved Sales 3 Million Backlog
Operator Training	77	13,500		●							●	2	●	Startup	?	?
Short-term Problem Solving	73-77	20,000	●	●	●	●		●	●	●	●	10	●	70 Companies	Yes?	Yes?
Totals		$432,175													$1,067,500-1,157,500	$1,571,000-2,153,000

BEST DOCUMENT AVAILABLE

sors, although suggestions could be accepted from any source. The Director, with the assistance of a Technical Committee, would screen the suggested projects and obtain proposals from competent researchers for those projects which appeared amenable to high industry impact. These proposals would be screened by both the Board of Directors and Advisory Board, and the approved projects would be implemented.

The Director of the Institute was to be the key individual. He was expected to have strong administrative abilities, experience with the furniture industry, and a research perspective. Professor Prak, who headed the Furniture Manufacturing and Management Program of the Department of Industrial Engineering, was appointed acting Director. He supervised the Institute through the Program Definition phase and led in the difficult search for a permanent Director. In the second year, 1975, Mr. John Markle, who had a distinguished career in the industry, accepted the directorship and the Institute appeared to have the perma-

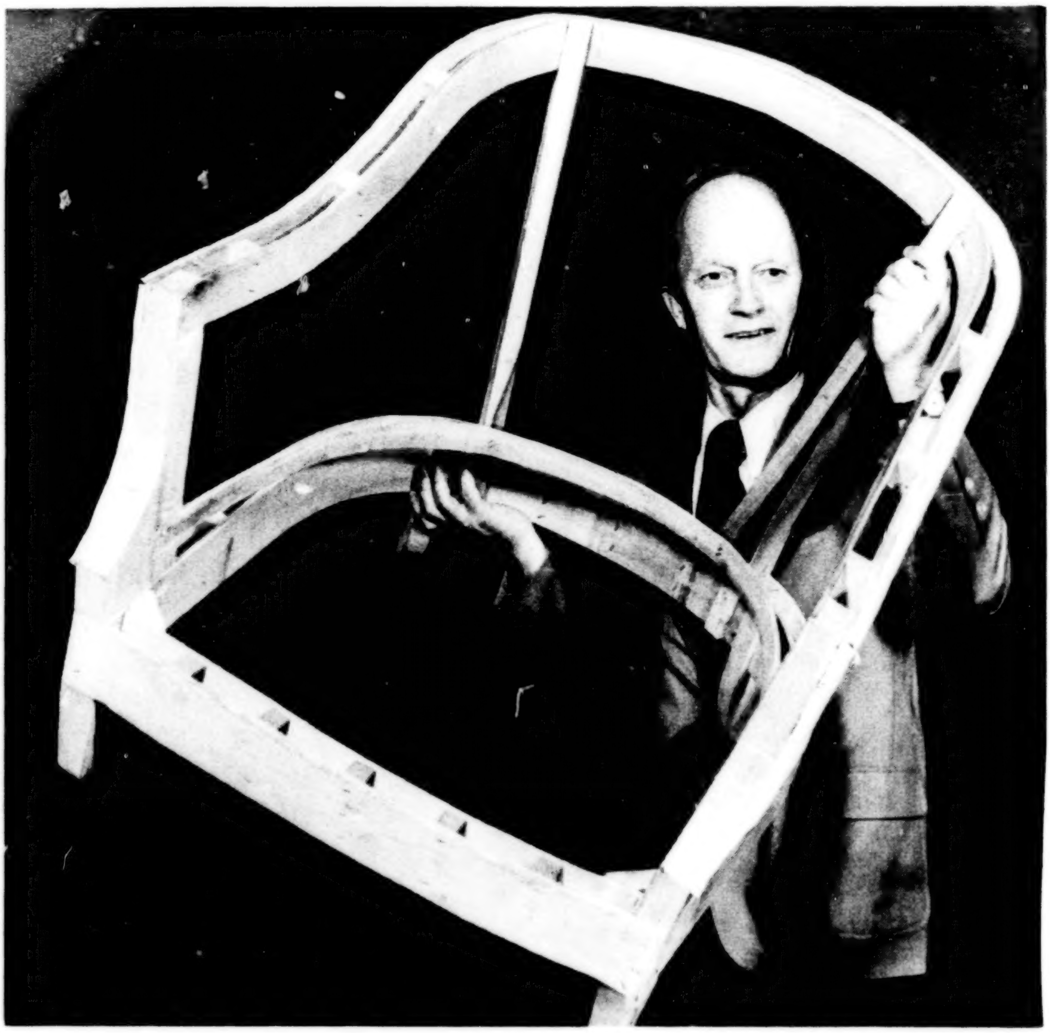


Figure 3. Clark Chair Frame.

88

nent leadership that would assure its success. This, however, was not to be the case. In one year, Mr. Markle resigned to return to industry and Mr. H. Burton, a member of the industry liaison staff of the Institute, was appointed Director. Mr. Burton, also with industry experience and very capable, undertook the leadership of the Institute for the final 2 years of NSF support. At this time, the Institute was considerably behind in its efforts to attract industry sponsorship, funding was below the target levels and decreasing, and the Institute's research program, although based on apparently solid projects, could not be expanded and was difficult to change.

The unhappy experiences of the Institute in finding a permanent Director had much influence on its eventual course. Perhaps it was a mistake to seek a person who had achieved considerable success in industry – his future rewards and successes will also be found in industry – and not in an academic institution, for his salary and future career growth would be based on academic standards. However, the experience of the Institute was affected by other circumstances as well.

The winter of 1974 saw the furniture industry, and the economy in general, enter a period of reduced sales and work force reductions. The climate was definitely unfavorable for recruitment of additional sponsors for the Institute, and the fees paid by existing sponsors, which are based on the number of employees decreased. The recession continued through 1975 and into 1976, key years in the Institute's history. The budget of the Institute was 6 percent less for 1976-77, the fourth year of the Institute, than had been proposed in 1973, despite the eroding effects of inflation. More importantly, the industry support level was not increasing to offset the programmed decrease of the NSF support level. Before this, it had become obvious that a radically different approach to industry sponsorship would have to be employed if the funding objectives of the Institute were to be met. Six sponsor companies had joined the Institute which, at the rate schedule established, resulted in total fees of around $60,000 per year. More than five times this annual income is needed to continue the Institute at its proposed level.

At this juncture, an effort was made to obtain sponsorship by an industry association, the Southern Furniture Manufacturers Association. Although success in this effort appeared to be possible, it did not materialize and the University has entered a retrenchment mode. The dean of Research at NCSU continues his support of the original concept and views the 5-year experiment as a valuable learning period from which a viable center will evolve. Now the Institute leadership is the part-time responsibility of a faculty member as these new directions are sought. The relationships between the university and the furniture industry remain strong and active.

The structure of the furniture industry and the nature of its product indicate that, for a cooperative research effort to be successful, continued substantial Government financial participation is necessary. Industry support for such a center should increase gradually. The rate of increase would be determined by the slow technology adoption process. Self-sufficiency, if it ever occurs, would result from demonstration of direct benefits of technology in the competitive marketplace.

THE NEW ENGLAND ENERGY DEVELOPMENT SYSTEMS (NEEDS) CENTER

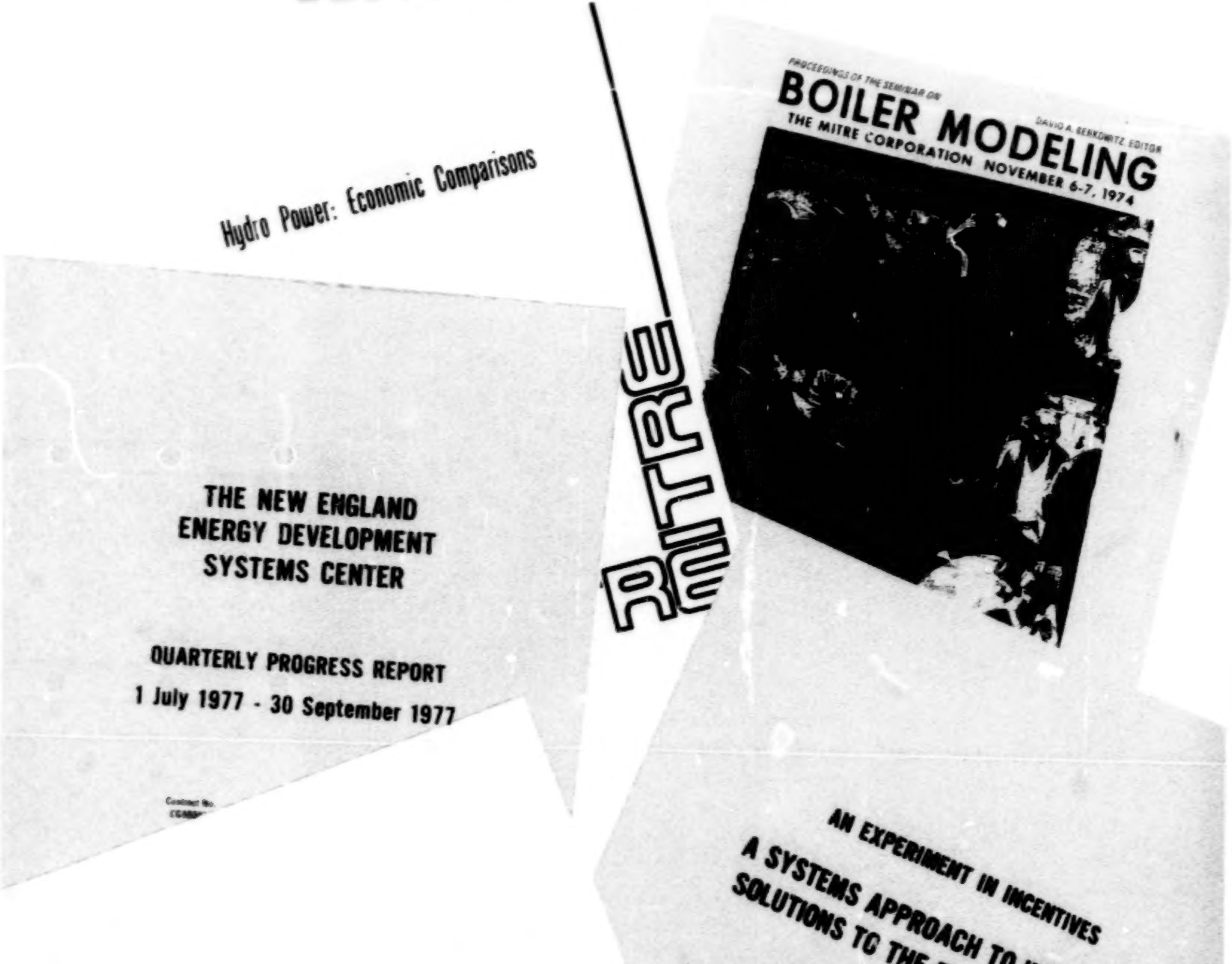
The salient and, in some respects, the most germane feature of the NEEDS Center is the brokerage role assumed by Mitre. Viewed in one respect, the injection of a third party (Mitre) between the primary parties (industries and universities) may be viewed as inhibitory to the goal of bringing them into a closer relationship. The thesis of the Mitre experiment, however, was that the university-industry gulf is so wide that a bridging organization is required to create a fruitful association. This concept gained support as one part of the University-Industry Cooperative Research Centers Experiment.

The NEEDS Center concept originally was directed toward New England electric utilities, was broadened to encompass a broader spectrum of regional energy concerns, and matured to include university-industry cooperative activities beyond the northeastern region of the country. (See table 7, figure 4, and table 8.) This maturation process appears to have been driven by perceptions of the success potential for the NEEDS concept. Originally, and accurately, it was perceived that electric utilities suffered from a lack of technological innovation. The universities offered a ready source for the missing expertise and, with the slackening of governmental support, they would welcome the opportunity to work on industry problems—with financial support by industry. Thus it appeared that a cooperative effort could not help but be successful.

Table 7. University Participation in NEEDS

Massachusetts Institute of Technology	Drum Boiler Modeling Energy Information System Energy and New England Economy
Dartmouth College	Solar Demonstration Project
Harvard University	Solar Energy Market Analysis
University of Texas	NEEDS Center Evaluation
University of Nevada	Snow/Ice Meter Development
University of Tennessee	Performance Analysis and Surveillance Drum Boiler System Modeling
Worcester Polytechnic Institute	Flow Test Facility
Purdue University	Laboratory for Study of Control Systems for Electric Automobiles
University of Pennsylvania	Residential Load Study
Northeastern University	Consumer Response to Load Management
Boston Architectural Center	Energy Conservation in Architecture
Boston College	Energy and New England Economy
University of Massachusetts	Hydroelectric Study

BEST DOCUMENT AVAILABLE



Hydro Power: Economic Comparisons

PROCEEDINGS OF THE SEMINAR ON
BOILER MODELING
DAVID A. BERKOWITZ, EDITOR
THE MITRE CORPORATION NOVEMBER 6-7, 1974

MITRE

THE NEW ENGLAND
ENERGY DEVELOPMENT
SYSTEMS CENTER

QUARTERLY PROGRESS REPORT
1 July 1977 - 30 September 1977

REGIONAL HYDROELECTRIC
RECLAMATION

JANUARY 1976

The Mitre Corporation
Bedford, Massachusetts

AN EXPERIMENT IN INCENTIVES
A SYSTEMS APPROACH TO INNOVATIVE
SOLUTIONS TO THE ENERGY PROBLEM

PROGRAM DEFINITION PHASE

JANUARY 1973

Prepared by
MITRE Corporation
assachusetts 01730

Figure 4. Activities of the NEEDS Center.

Even before the operational phase of NEEDS began, these perceptions had begun to mature and change. It was soon recognized that the electric utilities did not have more technological expertise because their operational and regulatory environment did not call for it. Maximization of benefits for owners of the utilities did not come from improving system efficiencies; regulatory commissions have not, even today, learned how to reward utilities for efficiency. Top management of utilities is not technically oriented and appears to prefer a low profile—steering clear of universities and Federal support with their concommitant exposure to public scrutiny. Thus, at the urging of its Advisory Group, the agenda of NEEDS was expanded to encompass the whole range of regional energy problems. However, this is better described by examination of the specifics.

The largest NEEDS project and one of the most successful—from an engineering viewpoint—began in the program definition phase in 1973. It involved a study of control system instability in a particular type of electric power generation system using a "once-through" boiler design. This project was concerned with specific generation units of the Boston Edison Company and was largely funded by that utility. Although this project was a technical success and the utility was well satisfied, the project involved only minimal participation by university researchers and thus, for the NEEDS Center, was not supportive of the broad objective. Other projects were developed that involved university participation. The development of a snow/ice meter with the University of Nevada and of a load management study in which both the University of Pennsylvania and Northeastern University participated are efforts which involved both substantial utility funding and major university participation in the mode originally perceived for the NEEDS Center.

With advice from the Advisory Council to broaden the perspective of NEEDS, activities focusing on regional energy concerns were fostered. Three projects resulted, two of which were funded by the New England Energy Policy Council. University researchers participated in these two efforts which were the

Table 8. Industry Participation in NEEDS

Boston Edison	Once-Through Boilers Snow/Ice Meter Development Load Management Study
New England Electric System	Snow/Ice Meter Development Load Management Study
Public Service Board of Vermont	Solar Demonstration Project
Electric Power Research Institute	Communications Alternatives for Automating Electrical Distribution Systems
Various*	Flow Test Facility Solar Demonstration Project Energy Conservation in Architecture

*For these projects, a number of industries have contributed directly to the universities in support of the projects.

92

creation of an energy information system and the study of energy perspectives and energy economics for New England.

Another type of project that NEEDS has fostered is usually initiated by a university, receives financial support and varying degrees of direct staff support from the NEEDS Center, and attracts additional support from an industry interested in the project. The Dartmouth College Solar Demonstration Project was the first example of this mechanism. That project led to a continuing evaluation of solar heating components and systems. This was followed by a study of energy conservation in architecture by the Boston Architectural Center, by efforts to design and establish a high Reynolds number flow test facility at Worcester Polytechnic Institute, and by efforts to establish a laboratory at Purdue University for the study of control systems for electric automobiles. All of these efforts are partially funded by the NEEDS Center and require support from industrial interests. The initiation and nourishment of such associations between universities and industries is the goal of the University-Industry Cooperative Research Centers Experiment, and these NEEDS Center efforts were directed to the incubation of new centers more than to strengthening itself as a viable center.

Despite the several successes of the NEEDS Center, it is apparent that its principal goals have not been met and that it will cease to exist. To probe the causes for this, one must examine its setting.

The NEEDS Center's stated objective was to test the feasibility of a lasting and mutually beneficial relationship between the university research community and traditional energy-related industry catalyzed by a nonprofit institution. Mitre Corporation proposed to NSF at the end of its program definition phase, a support level that was double that which was awarded. The award was based on a cooperative agreement with some unique features. Of the total $1,200,000 of NSF funds committed to the NEEDS Center for the 4-year effort, a minimum of one-half or $600,000 was to fund university research efforts (see figure 5). In addition, a ''minimum acceptable'' level of non-Federal funding equal to the NSF share was defined. The schedule of expenditures of the $600,000 available for support of the Mitre effort was limited, but it allowed expenditure of over 90 percent of the total in the first 2 years of the effort in anticipation that industry support would build up and be strongest in the last 2 years. An Advisory Group was organized to help provide guidance in the Center's development but did not play a significant role as the program progressed. The Mitre staff for the NEEDS Center was headed by Phil Vance and has a preponderance of experience in Air Force R&D activities, the primary mission of Mitre.

Much momentum had apparently been gained in the program definition phase of the NEEDS Center. The mid-1974 startup of the follow-on experimental phase saw a number of thrusts. There ensued a period in which Mitre personnel became involved not only with power system technology but also with State, regional, and national energy concerns, and they initiated cooperative activities with a number of universities. A total of 13 universities were to become involved in the NEEDS Center. By mid-1976, however, the early momentum appeared to slip away. Mitre found it difficult to keep its best

93

BEST DOCUMENT AVAILABLE

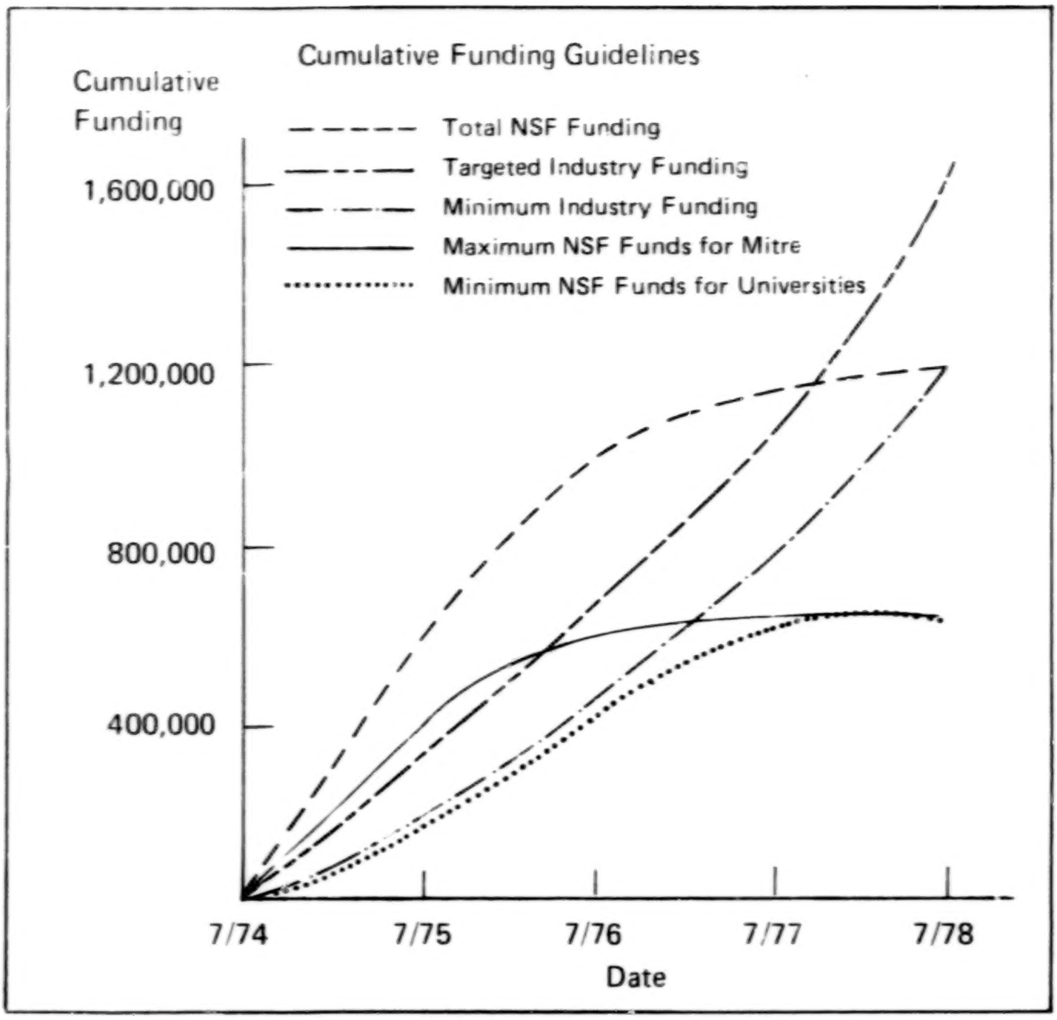


Figure 5. Funding Plan for the NEEDS Center.

people involved in development of programs in which the research would be carried out not by them but by the universities, the low-technology nature of utility interests became apparent, and non-Federal research funds in the energy field were sparse, at least in those areas on which Mitre has focused attention. It soon became apparent that the NEEDS Center lacked the essential ingredients that would permit its continuation beyond the experimental phase.

The failure of Mitre in meeting the NEEDS Center goals and the eventual demise of this part of the University-Industry Cooperative Research Centers Experiment is attributed to a number of factors by those familiar with it. These include:

- The Mitre staff perceives itself as participants in, rather than brokers of, research;
- The organizational setting is oriented to Air Force R&D;

- The NEEDS Center was not funded at the level that Mitre felt was required;
- The timing of the experiment in a period of economic recession worked against success.

Success and failure are relative – in this case and with the original goals, the NEEDS Center was not successful. However, if the Dartmouth, Worcester Polytechnic Institute, or Purdue projects continue, that is success. The barriers to research that are characteristic of utility management may have been significantly lowered by the successful experience of Boston Edison with the NEEDS Center.

The experience of the NEEDS Center indicates that, in the proper setting, the role of a broker in matching industry needs with university resources can work and be successful but that the cost of the brokerage function is approximately half of the total cost and requires Government funding. The expected result of such efforts would be the spawning of direct university-industry cooperation efforts, some of which would obtain self-sustaining permanence and others of which would have limited operational lifetimes.

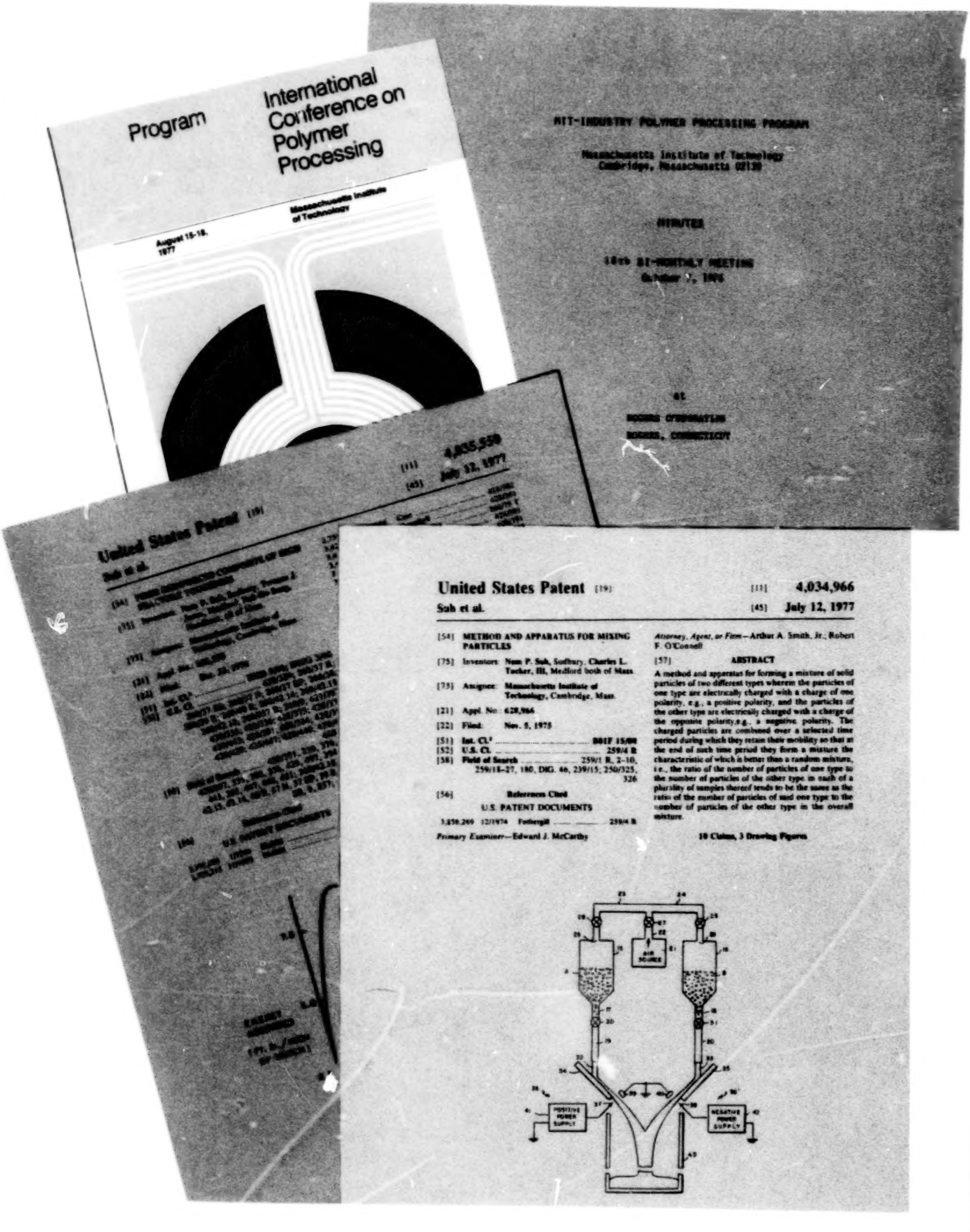
MIT-INDUSTRY POLYMER PROCESSING PROGRAM

When the program announcement for the University-Industry Cooperative Research Centers Experiment was issued, Professor Nam Suh of the Mechanical Engineering Department of MIT had a proposal ready. Professor Suh believes that the subsequent success of the Polymer Processing Program at MIT correlates to some extent with the fact that the need had been recognized and a plan formulated before announcement of the NSF program, not in response to the announcement. The timing of the announcement was fortuitous because otherwise it is probable that necessary seed money would not have been found. In any case, the result has been a highly successful demonstration that cooperative university-industry research programs are possible. The Polymer Processing Program is no longer an experiment. After 5 years, it is now completely supported by industry and has developed a strong durable operating mode (see figure 6 for some activities).

In 1973, the MIT proposal was one of 14 projects funded for the definition phase of the University-Industry Cooperative Research Centers Experiment. NSF provided $100,000 and industry support was obtained. The program began on July 1, 1973. By the end of Phase I, commitments from industry totaled $142,500 (see figure 7). The Phase II proposal was submitted in November of 1973 and funded at a level of $369,000 for the remaining 4 years of the experiment.

Professor Suh, with 15 years of experience in university and industrial research, had previously been employed by, and consulted with, USM Corporation, the first company to commit to the program. He has been director of the Polymer Processing Program since its initiation and actively participates in all of

BEST DOCUMENT AVAILABLE



Program

International Conference on Polymer Processing

Massachusetts Institute of Technology

August 15-18, 1977

MIT-INDUSTRY POLYMER PROCESSING PROGRAM

Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

MINUTES

18th BI-MONTHLY MEETING
October 7, 1976

at

ROGERS CORPORATION
ROGERS, CONNECTICUT

United States Patent [19]
Suh et al.

[11] 4,034,966
[45] July 12, 1977

[54] METHOD AND APPARATUS FOR MIXING PARTICLES

[75] Inventors: Nam P. Suh, Sudbury; Charles L. Tucker, III, Medford both of Mass.

[73] Assignee: Massachusetts Institute of Technology, Cambridge, Mass.

[21] Appl. No.: 628,966

[22] Filed: Nov. 5, 1975

[51] Int. Cl.² B01F 15/00
[52] U.S. Cl. .... 259/4 R
[58] Field of Search .... 259/1 R, 2-10, 259/18-27, 180, DIG. 46, 239/15; 250/325, 326

[56] References Cited

U.S. PATENT DOCUMENTS

3,850,269 12/1974 Fothergill .... 259/4 R

Primary Examiner—Edward J. McCarthy

Attorney, Agent, or Firm—Arthur A. Smith, Jr.; Robert F. O'Connell

[57] ABSTRACT

A method and apparatus for forming a mixture of solid particles of two different types wherein the particles of one type are electrically charged with a charge of one polarity, e.g., a positive polarity, and the particles of the other type are electrically charged with a charge of the opposite polarity, e.g., a negative polarity. The charged particles are combined over a selected time period during which they retain their mobility so that at the end of such time period they form a mixture the characteristic of which is better than a random mixture, i.e., the ratio of the number of particles of one type to the number of particles of the other type in each of a plurality of samples thereof tends to be the same as the ratio of the number of particles of said one type to the number of particles of the other type in the overall mixture.

10 Claims, 3 Drawing Figures

Figure 6. Activities of the Polymer Processing Program.

its phases. Professor Suh is a strong director, making the decisions on the research agenda, making creative contributions at critical junctures in the research, and providing a strong image to the industrial participants and university faculty and administration.

The operating mode of the program is centered around the Director (see figure 8). The three major functions in the operation of the center are administration, research, and the interactions with participating industries. The first of these is accomplished by the Director with advice and consultation of the Industrial Advisory Council and with institutional support from MIT. The Industrial Advisory Council consists of senior representatives of the industrial par-

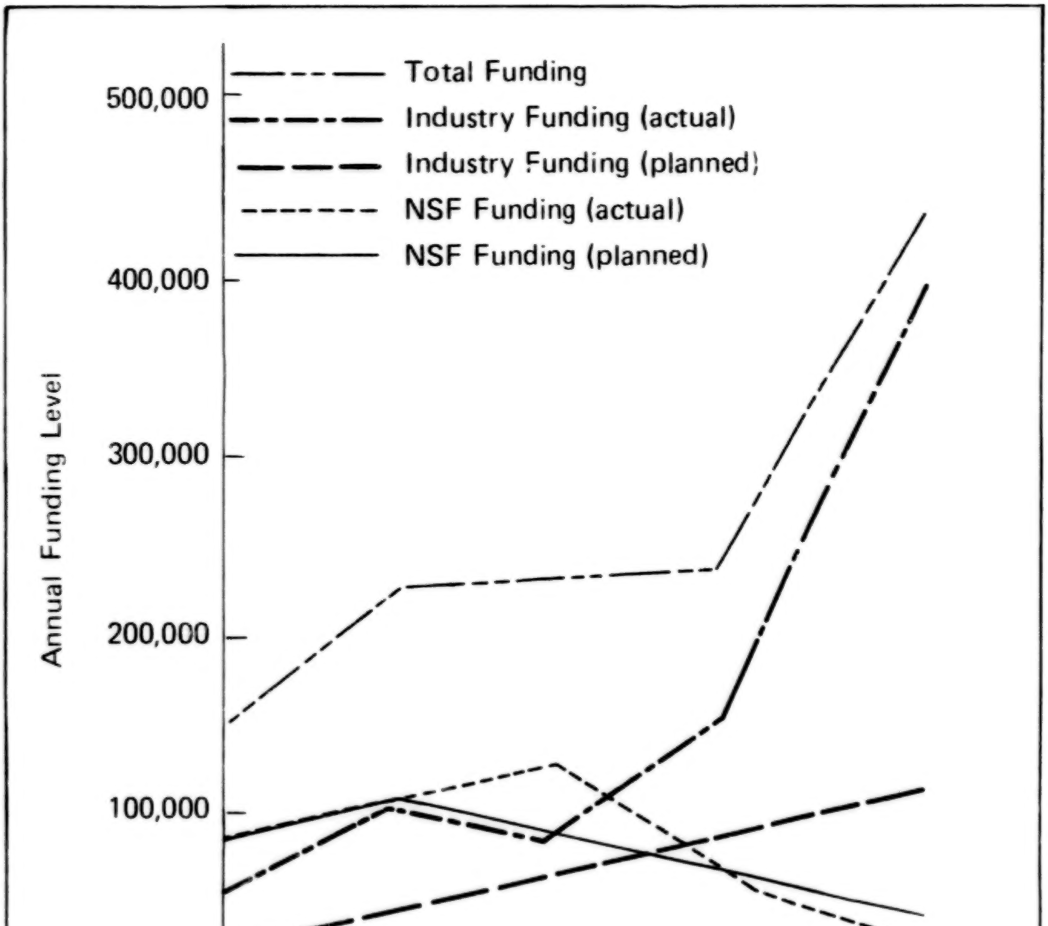


Figure 7. Funding of the Polymer Processing Program.

ticipants, the MIT Vice President for Research, the Director, a senior representative for MIT's Center for Policy Alternatives, and, during the period of NSF support, its Program Manager. The research function is performed primarily by participating graduate students supervised by the Director although with participation and supervision by other faculty and staff. Industry interactions are focused on bimonthly (now quarterly) Technical Review Meetings attended by 30 to 40 people about equally divided between MIT program staff personnel and representatives of the industrial participants. At these meetings, the research program is reviewed by the Director and the graduate students, and the participating faculty members give reports on their active research projects. Considerable interaction ensues between the program staff and industrial representatives—vice presidents and managers of research and operational entities. This operational structure has been highly successful, but it places a heavy burden on the Director who provides the leadership in each function.

The Polymer Processing Program got off to a good start with USM Corporation joining in the original Phase I proposal. That company, along with ITT Corporation and Rogers Corporation, committed a total of $142,500 at the time of the Phase II proposal. At the end of the 5-year experiment, the 12 companies listed in table 9 had become participants in the program (see figure 9), and the cumulative financial support by industry exceeded $1,000,000. Dr. Suh has noted that 12 participants probably would be the most that the program could accommodate and still provide adequate attention to each.

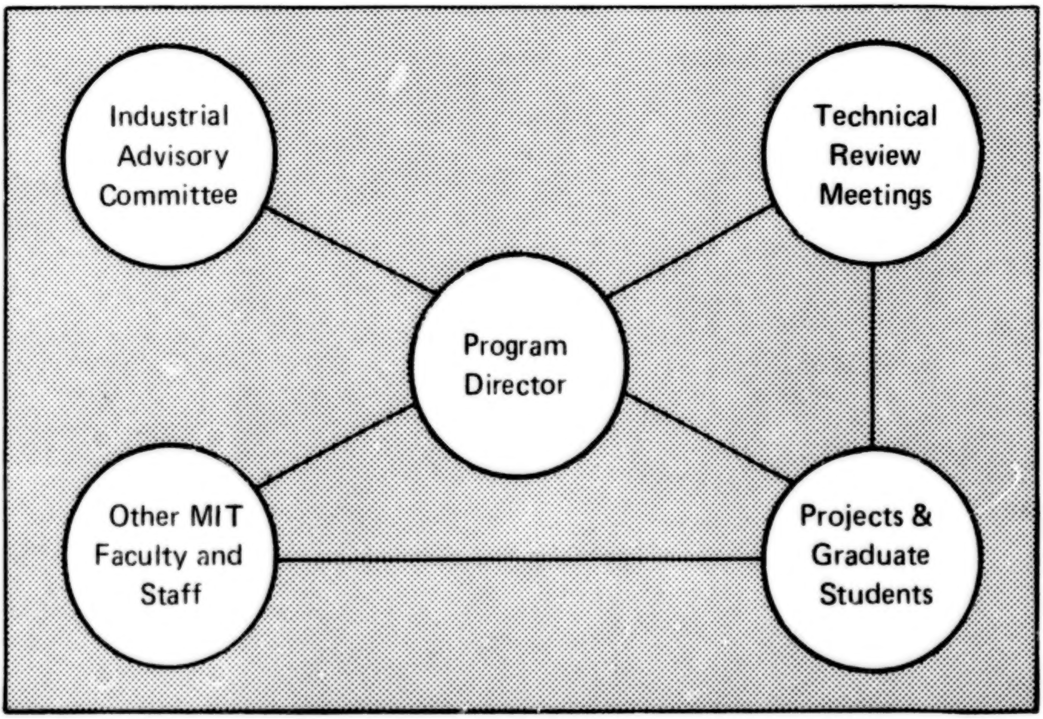

Industrial Advisory Committee
Technical Review Meetings
Program Director
Other MIT Faculty and Staff
Projects & Graduate Students

Figure 8. Operational Structure of the MIT Center.

98

BEST DOCUMENT AVAILABLE

Table 9. Industry Participation in the MIT/Polymer Processing Program

AMP, Inc.
Eastman Kodak Company
General Motors Corporation
Gleason Works, Inc.
Goodyear Tire & Rubber Company
Instrumentation Laboratory, Inc.
ITT Corporation
Kendall Company
Lord Corporation
Rogers Corporation
USM Corporation
Xerox Corporation

The research agenda is based on the needs of the polymer processing industry, specific needs of the member firms, and the intellectual and educational value of the projects. Project selection is, however, the responsibility of the Director. Originally, projects on impact forming, extrusion, processing of large thermosetting parts, production system control, and process modeling were proposed. Other projects were added and some were terminated during the course of the program. Altogether, 27 projects were initiated with the shortest project duration being 6 months and the longest being 5 years. No more than 15 projects were active at any one time. (See figure 10 and table 10.) The staff of the program at the end of the 5-year experiment consisted of about 28 people, 21 being students. Support for the program is growing, although no product has been commercialized and only two patents issued (8 more U.S. patents have been applied for).

Evaluation of the Polymer Processing Program is being carried out by MIT's Center for Policy Alternatives and is based on subjective assessments by the participating firms and on objective measures such as level of support, number

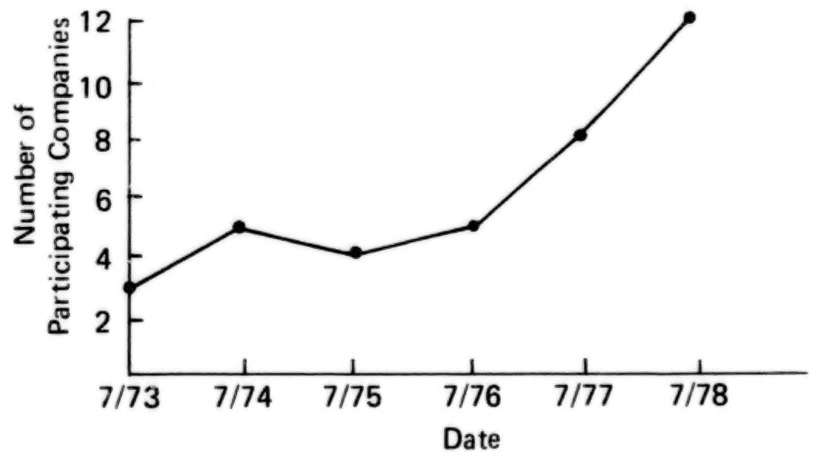


Figure 9. Industry Participation in the MIT/Polymer Processing Program.

BEST DOCUMENT AVAILABLE

Table 10. Projects in MIT/Polymer Processing Program

- Flexural Strength of Phenolic/Asbestos Composites
- Impact Forming of Polymers
- Direct Forming of Thermoplastic Powder
- Mixing of Reacting Liquids by Concentric Cylinder Mixer
- Modification of Injection Molding Techniques
- Screwless Extruder
- Recycling of Thermosets and Elastomers
- Improvement of Impact Resistance of Fiber-reinforced Polyester
- Mathematical Modeling of Injection Molding
- Hybrid Mixing (polyurethane mixer)
- Impingement Mixing
- Adhesive Tape (adhesion and related problems)
- Activation of Blowing Agents
- Printed Circuit Materials
- Accelerated Testing
- Mixing of Powder
- Augmentation of Heat Transfer in Plastisol
- Graphitization
- Rubber Mixing (mixing of elastomers)
- Friction and Wear of Fiber-reinforced Plastics and Polymers
- Picker Stick Treatment (increasing damping in wood)
- Metering Device
- Melting Device
- Removal of Flash from Plastic Parts
- Sink Marks in Sheet Molding Compound
- Glass Reinforcement
- New Injection Mold Construction

of projects, number of participant companies, and level of MIT faculty and student participation. Objective data are given in figures 9 and 10. Analysis of the subjective assessments, obtained at the bimonthly (now quarterly) meetings of participants, has indicated that industrial participants have become progressively more involved with the program, have found the program to be progressively more useful, perceive the research as being of high quality, and have

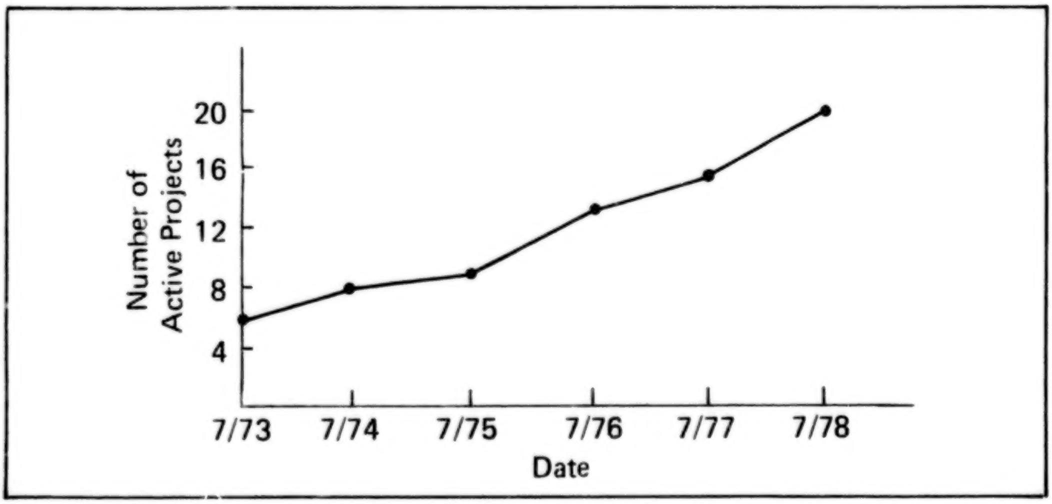


Figure 10. Number of Active Projects in the MIT/Polymer Processing Program.

respect for the abilities of the student researchers.* In another analysis of factors inhibiting industry participation, it was found that cost of participation was the primary deterent to participation.**

The Polymer Processing Program at MIT is the most successful of the University-Industry Cooperative Research Centers. At the end of the 5-year period of NSF support, the Polymer Processing Program has become completely self-supporting with an annual budget exceeding $500,000 (figure 7). The total industry funding of $1,100,000 was more than twice the funding provided by NSF during this period. The success of the program has resulted in attempts to replicate it by other Government agencies and in other academic settings. This success has conclusively demonstrated that university-industry cooperative research is a viable concept. It remains to be determined which of the unique conditions obtained for the Polymer Processing Program at MIT are necessary for success and whether these can be obtained in other settings.

---

*Draft of progress report for period January 1976 through June 1977.

**Hays, George G., *An Analysis of Factors Influencing Industrial Participation in the MIT-Industry Polymer Processing Program,* S. M. (Sloam School) and S. B. (Mechanical Engineering) Thesis, MIT, September 1977.

COMPOSITE

The immediate measures of success for the University-Industry Cooperative Research Centers Experiment are industry support, faculty/student participation, active industry involvement, and university acceptance. The degree with which these measures have been obtained by the experiment and by the centers is discussed in the following paragraphs. The ultimate measures of success, as they differ from the immediate measures, are not fully determinable at this time; their development extends over a longer time period.

The most important indicator of success is the continued viability of the centers after the termination of NSF support. The fact that MIT has, in the Polymer Processing Program, a vibrant activity fully supported by industry gives a positive result for this measure. The almost certain demise of the NEEDS Center and the necessary retrenchment for the Furniture R&D Applications Institute lessen but do not counterbalance MIT's success. A prime purpose of the experiment was to prove that operation of a center independent of Government support was possible. This has been proven. Of almost equal importance is the demonstration that, for certain industries, continuing cooperative research efforts will require continuing Government participation. Examination of the circumstances that determine the degree and duration of such continuing financial support provides a basis for establishment of policy for a comprehensive Federal program in meeting this important national need.

The participation of faculty and students in center activities varies considerably. It is notable that the most successful center—that at MIT—had the strongest student participation. In fact, the students produced the results and gave the reports. This indicates strong, effective direction by the Polymer Processing Program leadership. Other faculty participation has been limited. NEEDS Center projects carried out at its participant universities included student participation but not at a high level. The focus of NEEDS on program building such as for the test facility at Worcester Polytechnic Institute and the electric automobile laboratory at Purdue University dictated a high level of faculty participation but little, if any, participation by students. In the research areas in which the Furniture R&D Applications Institute was active, there were few, if any, graduate research programs; therefore, all of the research was apparently carried out by the faculty and staff. In summary, participation appears to be that shown in table 11.

Industry involvement in center activities has occurred in a variety of ways. These include:

At the Furniture R&D Applications Institute—

- Sponsorship*
- In-plant workshops*
- Seminars and short courses

102

- Industry Advisory Committee*
- Cooperative projects and extension*
- Requests for assistance

At the NEEDS Center—

- Project sponsorship*
- Coparticipation in university projects
- Advisory group

In the Polymer Processing Program—

- Sponsorship*
- Industry Advisory Council*
- Research review meetings*
- Cooperative research

The activities indicated by an asterisk (*) are those which, through the level of participation, appear to be most meaningful.

As a measure of university acceptance, the Polymer Processing Program appears to have produced the most impact. Most important is the observation by the center director that MIT faculty personnel have changed from a somewhat negative to very positive attitude toward industrial R&D. Early in the program, there were doubts as to whether such research would meet the academic quality requirements of their institution. These doubts no longer exist and attempts are being made to emulate the Polymer Processing Program for other industries. The university administration is strongly supportive of the center and takes pride in its success. This is impacted positively by noting the relatively high ratio of industrial funding obtained by the Polymer Processing Program (see figure 11).

The overall impact of the NEEDS Center on universities is much less because its activities have been dispersed among a number of universities with a limited program at each. The visibility of the efforts are thus minimal at any one institution.

The Furniture R&D Applications Institute operates more as an extension

Table 11. Participation in Center Operations

	Polymer Processing Program		NEEDS Center		Furniture R & D Applications Institute	
	Leadership	Research	Leadership	Research	Leadership	Research
Faculty	High	Some	Some	High	Some	High
Students	Some	High	None	Some	None	Minimal
Staff	Some	Some	High	High	High	High

BEST DOCUMENT AVAILABLE

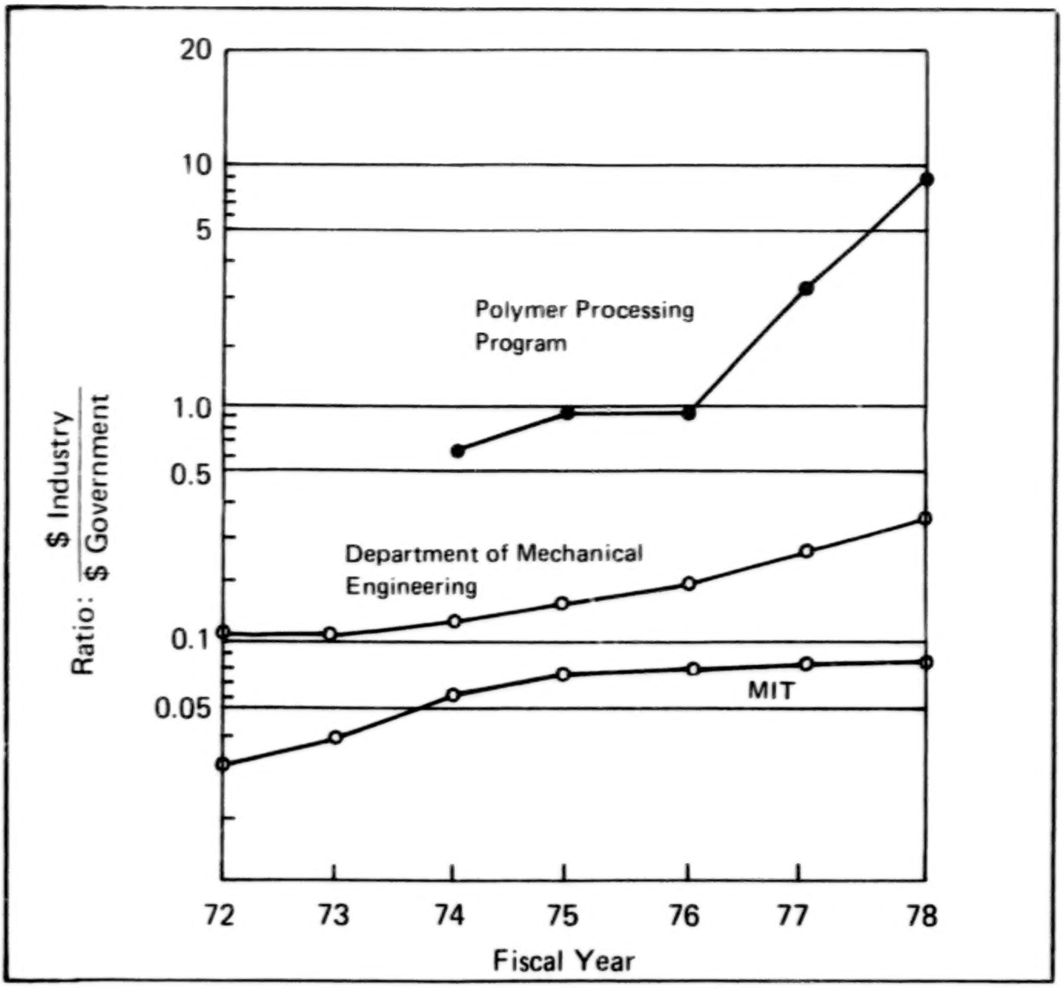


Figure 11. Ratio of Research Funding: Industry/Government.

than as an academic research effort, and its leadership was not from the regular faculty. Its impacts have thus not been in the academic mainstream of the university.

In terms of longer term goals of the University-Industry Cooperative Research Centers Experiment, equally positive results are indicated (see page 6). Certainly the investment of non-Federal funds in academic R&D has increased; industry has invested over $3,000,000 in the centers' activities. This indicates that industry is finding increasing value in academic research support. Research results and techniques developed at the centers are being used in industry and, in the normal slow process of technology transfer, this utilization will expand. In certain industries, the technology transfer processes are being accelerated. All of the centers have succeeded in redirecting academic research to real and important industry problem areas. Many of the barriers to academic-industrial cooperation seem to have been lowered. It has been shown that such programs can work and be productive.

The nature of the industrial participation in the cooperative research efforts varies widely. At one extreme are large companies with substantial research activities such as General Motors, Xerox, and Kodak, and at the other extreme is a small construction firm participating in the NEEDS solar technology program at Dartmouth. The more substantial participation has come from the large research-oriented companies that can understand and use the research outputs of the cooperative efforts. Companies with little research background, such as the utilities and furniture companies, are traditionally conservative with respect to new technology, are not structured to take advantage of research results, and are traditionally dependent on their suppliers for whatever changes they adopt. For this latter group, the research must be more oriented to short-term problem solving and the barriers to participation in cooperative research are more difficult to overcome.

It thus appears that cooperative research for high technology industries is more readily implemented and requires less Government support. Because the products of the cooperative effort would be primarily supportative of internal company R&D, the impact of the results would often be marginal and difficult to assess. On the other hand, cooperative research with low technology industry would seem to be more difficult to implement and would require more Government funding but would have a greater impact because of the greater need.

CONCLUSIONS

The following four overt conclusions of the University-Industry Cooperative Research Centers Experiment as of the termination of NSF support are given in order of significance:

1. **The concept of industry-supported university-performed R&D is viable.** Corollaries of this conclusion include:
   - Industry accepts the fact that university R&D can provide direct, usable benefits;
   - Industry is willing and able to pay for the cost of such research and to participate in defining the agenda and evaluating the results;
   - Patent ownership and proprietary rights are barriers to cooperation but are amenable to rational resolution.

The original conception that such barriers as costs, patent rights, publications, research utility, and the basic differences between universities and industry would inhibit cooperation have been dispelled; although under different circumstances, they could become significant. The most viable concept that has emerged—that of a faculty-student research effort directed to a set of well-defined needs of, and supported by, a small group of firms—is represented by the Polymer Processing Program. The least viable concept appears to be the third-party R&D brokerage arrangement working between a larger group of companies and dispersed university research resources. The former arrangement benefits greatly from continuity of the program and the personalized attention given to sponsors' needs.

2. **University faculty will accept industrial problems as proper subjects for academic research.**

Academic research is sometimes viewed as having a sacrosanct nature, unmotivated by practical concerns, and in search of knowledge as perceived by the investigator. The freedoms permitted under the Government research grant system and the peer review process are supportive of this view. If this view were entirely true, industrial research would be impossible in the university. If it were not partially true, university research would lose its vitality. The Cooperative Research Centers Experiment indicates that problem-oriented industrial research is well accepted by faculty researchers so long as they retain the freedom of selecting the approach to solution and judging the depth of the investigation. Opportunities to apply fundamental knowledge and to be creative appear most important.

106

3. **University-industry cooperative research appears to be a solution to the diminution of industrial R&D and the need for higher productivity and for greater technological content in the products of U.S. industry.**

The pooling of resources to attack a common technology area allows industrial research in areas that no one company could afford. This mechanism is most applicable when the research subject is not product specific. Delayed publication of research results and limited dissemination of the practicum provide sponsors with a competitive advantage in utilization. The utility of the products of cooperative research have been demonstrated in the furniture, polymer processing, and energy-related industries.

4. **The participants in cooperative research must be carefully matched in order to obtain a lasting partnership, and the characteristics of the industry must be considered in establishment of funding goals.**

The extant university research capabilities and the industry interests are obviously well matched in the Polymer Processing Program. In the Furniture R&D Applications Institute, elements for a successful matchup are certainly present. It is easy to visualize circumstances, however, where the participants are mismatched and essential communication cannot occur. A university physicist, in general, could not communicate with a furniture company nor would the integrated circuit industry communicate well with an academic topologist.

With respect to funding goals, it has been demonstrated that, for one type of industry, a cooperative research center can become independent of Government support in 5 years. Other industries with similar favorable circumstances exist. However, there are many industries for which more Government funding would be required and for a longer duration, in some cases, indefinately. It is also recognized that in every industry there are companies which are more suitable for, and have a great propensity for, participation in cooperative research than the remaining companies. These must be targeted to obtain a successful center. Thus, there is a full spectrum of opportunities for establishment of Government-university-industry cooperative research centers.

BEST DOCUMENT AVAILABLE

SECTION IV.

An Analysis of the National Science Foundation's Experiment on Federal Actions to Accelerate Utilization of Civilian Oriented R&D

108

An Analysis of the NATIONAL SCIENCE FOUNDATION'S EXPERIMENT ON FEDERAL ACTIONS TO ACCELERATE UTILIZATION OF CIVILIAN ORIENTED R&D

PREFACE

This experiment on Federal actions to accelerate utilization of civilian-oriented R&D is one of several initiated by the National Science Foundation to identify, test, and evaluate incentive strategies and institutional arrangements for stimulating technological innovation in both the private and public sectors.

Specifically, the experiment is an attempt to examine and evaluate various incentive strategies employed by Federal agencies to enhance the commercial utilization of the results of this Federally funded R&D. This assessment is based upon observing the makeup and progress of 33 Federally sponsored R&D programs that have innovative potential.

It is expected that the results of the experiment can provide guidance to Government and industry for reducing time for utilizing Federal R&D results and, at the same time, decreasing the Federal R&D costs for involvement.

R. M. Colton
April, 1979

ABSTRACT

The Federal Government annually expends billions of dollars for civilian oriented R&D*. Incentive strategies employed by Federal Agencies are presumed to enhance the commercial utilization of the results of this R&D. To evaluate this enhancement the National Science Foundation has sponsored a four year study under NSF-C-RDI74-23241. This study was conducted by Innovative Systems Research, Inc., Pennsauken, N. J. The study commenced June 24, 1974 and was completed on June 30, 1978.

The collection of longitudinal project specific data needed to evaluate incentive strategies, was made possible through both the development of a theoretical framework and the establishment of a long term working rapport with the Department of Energy, Environmental Protection Agency, and the Department of Commerce. These agencies are representative of various government agencies sponsoring civilian oriented research and development.

The goal of this study was to provide program decision makers with information on the programmatic effects of incentive strategies on the ultimate utilization of R&D results. Insight into these effects, obtained through the observation of 33 Federally-sponsored R&D programs, may be used to encourage strategies which can decrease the time until the outputs of Federal R&D are utilized by industry and decrease the Federal R&D costs for involvement.

The objectives of this study were:

- *to analyze the effects of those incentives which have in the past been employed by Federal Agency Program Managers (e.g. the provision of government testing facilities, the establishment of industry advisory panels, and the interagency transfer of funds);*
- *to assess the characteristics of those barriers which have impeded program success (e.g. union problems, lack of technical specifications);*
- *to provide a methodology and database for assessing the effectiveness of alternative strategies for use by Federal Agency policy and decision makers;*

---

* "Science and Technology Annual Report to the Congress," National Science Foundation, NSF 78-60, August 1978.

111

- *to develop indicators and a methodology that can be used by researchers studying the innovation process.*

Documented and interview data was obtained through the cooperation of Executive and Program Manager personnel in the three agencies. Of particular importance to the study was access to Program Managers' personal files. That information, in conjunction with structured interviews which focused on Program Managers' perceptions of project decisions and their outcome, provided the study's basic data.

Three models were developed during the completion of this study. The *Attributes* Model has distinguished the specific characteristics, or "attributes," of individual incentive and barrier conditions; the *Interim Components of Success* (ICS) Model measured the progress of any project towards commercial utilization; and the *Research and Development Similarity* (RDS) Model estimated the similarity among various R&D projects. The models are essentially statistical and the data analysis required the use of parametric and non-parametric statistics.

The structure and conduct of this study was guided by three fundamental hypotheses. For those civilian oriented R&D projects which have had substantial Federal funding, agency incentives can:

- shorten the time required to achieve commercial utilization of Federally sponsored R&D
- lower the overall cost of commercial utilization of industry conducted, Federally sponsored R&D
- increase the probability that an industry performed Federally sponsored R&D project will be commercially utilized

The study results outlined below support these hypotheses and in addition, several other categories of specific conclusions have been reached. These conclusions concern the:

- influence of different types of incentives upon project progress by R&D stage
- characteristics of incentives by type

- effects of incentives under various R&D conditions such as the number of competing technologies and the technical state of the R&D
- characteristics of barriers by type

The study has demonstrated that a formalized system can be developed to track the influences of incentive strategies on R&D projects and on the progress of the projects themselves. The results of this study can be used to inform Agency Program Managers about the impact of incentives which have been used in the past, and allow them to make inferences concerning the success of similar incentive strategies in the future.

TABLE OF CONTENTS

Abstract
-v-

Summary
1

Methods and Models
9

Results - Study Findings
21

Appendix A

SUMMARY

OBJECTIVES

Management of civilian oriented R&D projects (such as transmission systems for transportation vehicles or pollution control equipment) differs from that of mission oriented R&D projects (such as missile systems and the Space Shuttle). The difference arises because the former is performed by the private sector for the Federal government with industry and/or the civilian population as the ultimate consumer, while the latter is performed by the private sector for the Federal government with other governmental agencies, such as DOD, and NASA as the ultimate consumer.

This difference in user population is reflected in the strategies required of agency decision makers to stimulate utilization. With civilian oriented R&D, the government must often rely upon inducements other than contractual funding to entice the private sector to utilization. Such inducements are not as important to Federally oriented R&D, since Federal contractual funding often completes the product development cycle.

As a result of this difference in orientation, Program Managers for civilian oriented R&D should be aware of and use strategies that can accelerate the progression of projects from research definition, through applied research and development to profit oriented utilization by the private sector. It is therefore the objective of this study to provide Program Managers with a methodology for choosing among alternative incentive strategies to stimulate utilization of R&D results. By applying the known results from past and current projects, it is expected that Program Managers will be able to more efficiently manage their current and future projects.

HYPOTHESES

During the course of the study, it was noted that all projects examined were to one degree or another affected by Agency incentives. Accordingly, it was not possible to establish a baseline of unaffected projects. These interim results were used to refine the study's hypotheses as noted. For those civilian oriented R&D projects which had substantial Federal funding, the study's hypotheses are:

- Agency incentives can shorten the time required for industry to achieve commercial utilization of Federally sponsored R&D
- Agency incentives can lower the overall cost to commercial utilization of industry conducted, Federally sponsored R&D.
- Agency incentives can increase the probability that the results of an industry conducted, Federally sponsored R&D project will be commercially utilized.

It should be noted that the study has reached conclusions of a more detailed nature than the simple support of these hypotheses. In particular, the study has drawn specific conclusions with regard to the following:

- the influence of various types of incentive actions upon project progress by R&D stage (ICS Model);
- the characteristics of incentives by type of incentive (Attributes Model);
- the effectiveness of incentives under varying R&D conditions (Attributes Model);
- and the characteristics of barriers by type of barrier (Attributes Model).

BASIC ASSUMPTIONS

Conduct of this study has been predicated upon three basic assumptions. *First and foremost among these is the assumption that Federal premeditated actions, viz. incentives, can positively affect the course of civilian oriented R&D.* It is most important to note that this study has focused on those incentive actions which can be applied at the discretion of the Program Manager, (e.g. the use of letter contracts; requiring multiple user participation; letters of authorization; coordinating private sector

116

contractors; letting contracts for testing; no-cost time extensions and changes in technical scope of the work effort). No attempt was made to collect data on the broader agency policies which are implemented at a level higher than the Program Manager, (e.g. the issuance of exclusive/non-exclusive licenses; the existence of formal technology transfer groups; and the preference for demonstration programs).

The second assumption is that R&D projects can be characterized by the barriers that impinge upon them. Barriers have been characterized by a number of factors including the ease with which the barrier can be overcome, the urgency to overcome the barrier, and the extent to which the barrier increases the time and cost to R&D utilization. At this level there is no need to characterize barriers by their type, (e.g. Economic/Financial, Market, Technical, etc.) as is done in the following pages. Rather, it is important to assume that the complete set of variables that uniquely delineate the blockages that affect innovations, i.e. barriers, has been identified. Furthermore, it has been assumed that the extent to which each project is impacted by similar barriers can be an indicator of project similarity.

The third assumption is that the characteristics, or attributes, of barriers and incentives can be reliability denoted by the perceptions of Program Managers in terms of the impacts of incentives and barriers upon their projects. It is also assumed that with proper assistance the cognizant Program Managers can identify most barriers which impact their respective projects.

MODELS

Three models were developed to facilitate the conduct of this study. The *Research and Development Similarity* (RDS) Model was utilized in the grouping of observed projects on the basis of similarity as measured by various program characteristics such as the ultimate user (Federal, State and Local governments vs. private sector manufacturers and consumers, (the number of competing technologies, the technical state of the R&D (advanced vs. state-of-the-art) and the agency sponsoring the R&D. The RDS Model was initially employed in two areas, the selection of a representative sample and the determination of the responses of similar projects to similar incentives.

117

The *Interim Components of Success* (ICS) Model was developed to provide an overall, general estimate of a project's progress towards commercial utilization by allowing "ICS scores" to be tabulated at various points in the life of the particular project. Through the inspection of instances in which various incentives were applied, and the associated movement in a project's ICS score, the relative strength of various types of incentives have been estimated.

The *Attributes* Model was designed to identify several of the major characteristics of the incentives and barriers which have been seen to impact the progress of those projects observed in this study. With regard to incentives, those characteristics include among others: the ability of the incentive to impact the time and cost to commercialization, the cost to implement the incentive, the ease with which the incentive can be applied, and the time needed for the incentive to demonstrate its effects. With regard to barriers, distinctive characteristics include among others: the ease with which the barrier can be overcome, the relative ease with which the barrier can be perceived, the extent to which the barrier impacts the time to utilization, and the impact of the barrier upon the cost of the project. The *Attributes* Model can therefore provide the Program Manager with reasonable estimates as to the specific characteristics of various incentive alternatives as well as barrier conditions. The classification of such incentive and barrier types is presented in Table 1.

TABLE 1. CLASSIFICATION OF INCENTIVE AND BARRIER TYPES

ECONOMIC/FINANCIAL	POLICY
INFORMATION TRANSFER	ORGANIZATIONAL
LEGAL	REGULATORY
MARKET	TECHNICAL
NEED	

Specific examples of each type of incentive and barrier are noted in the following section (pages 17-20) where each of the referenced models is discussed in greater detail.

RESULTS AND CONCLUSIONS

As noted earlier, this study of Federal incentives has generated several categories of conclusions which can be of assistance to Program Managers in the management of their respective R&D projects, and specifically in the application of various incentive actions which may be available. The outline provided below makes brief reference to each of those conclusions, while the following section entitled "Results - Study Findings" discusses the conclusions in greater detail. Also in this summary, incentive and barrier actions and conditions are referred to by type, *i.e. Economic/Financial, Technical, Regulatory, etc.* The reader is therefore referred to the "Methods and Models" section, which describes those specific actions and conditions which have been included under each type (Pages 17-20).

The Influence of Various Types of Incentive Actions Upon Project Progress by Stage of the R&D Process

To aid in this analysis three stages of the innovation process have been defined. Those incentives which have been estimated to be most effective in increasing the probability of commercial utilization of the results of the Federally sponsored R&D have been grouped by the stages noted below.

- *Stage I - Research Definition to Applied Research*
- *Stage II - Applied Research to Development*
- *Stage III - Development to Utilization*

Those incentives which have been identified as being most effective are listed in Table 2 according to their estimated order of effectiveness.

TABLE 2. EFFECTIVENESS OF INCENTIVE TYPES IN INCREASING THE PROBABILITY OF UTILIZATION BY R&D STAGE

STAGE 1	STAGE 2	STAGE 3
LEGAL	LEGAL	MARKET
POLICY	ECONOMIC/FINANCIAL	TECHNICAL
TECHNICAL	TECHNICAL	ORGANIZATIONAL
	INFORMATION TRANSFER	LEGAL
	ORGANIZATIONAL	ECONOMIC/FINANCIAL

119

As is apparent, not all of the incentive types identified in the previous section are represented in any one of the three stages noted. This is so because several of the incentive types were not observed to be applied during the life of the R&D projects included in the study sample. The scarcity of such observations has itself indicated the relative unpopularity of the use of incentives such as those defined as Regulatory and Need. The results alluded to Table 2 were obtained through application of the ICS Model.

The Characteristics of Incentives by Type of Incentive

With regard to the characteristics found to be associated with various types of incentives, the Attributes Model has provided some insight. Specifically, it has been estimated that those incentives:

- most costly to implement are *Technical, Economic/Financial, Policy and Market.*
- which demonstrate their impacts over a relatively short period of time are *Legal, Economic/Financial, and Technical.*
- which are easy to apply are *Market, Information Transfer, and Legal.*
- which can be implemented in a short period of time are *Economic/Financial, Policy, Information Transfer and Legal.*

In addition the similarity of incentive types, according to a variety of attributes, has been estimated. In this regard the following pairs of similar incentives have been defined:

- *Legal and Technical*
- *Economic/Financial and Policy*
- *Information Transfer and Market*

The Effectiveness of Incentives under Specific R&D Conditions

Concerning the effectiveness of various incentive actions under specific R&D conditions, several conclusions have been reached. Significant variations in incentive effectiveness were examined for projects grouped by three R&D conditions; product vs. process, competing technologies, and technical state (i.e. advanced vs. state-of-the-art), while the "effectiveness"

120

of each incentive has been expressed in terms of: controllability by the Program Manager, impact upon the cost to utilization, and impact upon the probability of utilization.

With regard to the "controllability" of various types of incentives, the following results have been noted:

- *Legal and Economic/Financial* incentives are more controllable by the Program Manager when applied to projects which are advanced technologies,
- *Policy* incentives are more controllable by the Program Manager when applied to projects which have competing technologies,
- *Policy* incentives are more controllable by the Program Manager when applied to projects which involve a process rather than a physical product.

Concerning the influence of incentives upon the cost to utilization, the following results have been noted:

- *Legal* incentives are better able to lower costs in projects which are advanced technologies,
- *Technical* incentives are better able to lower costs in projects which are state-of-the-art technologies,
- *Technical* incentives are better able to lower costs of projects with competitive technologies compared with technologies developed in the absence of competition.

With regard to the influence of incentives upon the probability of utilization, the following distinction has been noted:

- *Organizational and Technical* incentives are better able to increase the probability of utilization when the project is a state-of-the-art technology

The Characteristics of Barriers by Type of Barrier

Barriers were also analyzed to estimate the extent to which each type possesses various characteristics. The conclusions reached indicate that those barriers to commercial utilization;

- which cause the most serious delays in the time to utilization are *Market, Information Transfer, Organizational and Legal.*
- which increase project costs the greatest are *Regulatory and Technical.*
- which are usually internal to the Federal agency are *Regulatory, Need, and Legal.*
- which are most difficult to perceive are *Policy and Regulatory*
- which are most urgent to overcome are *Information Transfer, Policy, Organizational and Legal.*

In addition, similarity among the various types of barriers to success was estimated according to the extent each barrier type displays various attributes such as those noted. In this regard the following pairs of similar barriers have been identified:

- *Legal and Organizational*
- *Economic/Financial and Market*
- *Need and Organizational*

METHODS AND MODELS

UNIT OF ANALYSIS

The unit of analysis for this study is the Federally sponsored, extramurally conducted *R&D project* (i.e. product or process), that is directed towards a defined goal. Such a definition has permitted the following of a "project" from one agency to another and through parallel demonstration awards. It follows therefore that the *R&D project* can have single or multiple contracts and/or grants.

The goal of the *R&D project* is strongly dependent upon the sponsoring agency's motive. In some cases the goal is for the private sector to utilize the developed product or process in a profit making product line. In other cases the agency's primary goal is to alleviate an existing condition such as the amount of energy consumed or the degree of environmental pollution created. In these latter cases, the commercial utilization of the R&D is of secondary importance to the implementation of regulation.

APPROACH

The overall approach used in this study is depicted in Figure 1. A significant advantage of this study when compared with other policy/technology related studies, has been the extensive period of time allocated to the formulation of the study's methodological approach. Of prime importance during the structuring phase was the categorization and definition of information elements, such as user, physical product, intellectual product, legal influence factor, etc. As a result of this attention to detail, the three models were developed. These models were subsequently tested with available data and implemented during the study's analytical phase.

AGENCY CONTACT

Concomitant with the analytical development, contact was made with several Federal agencies which fund civilian oriented R&D. The mechanism for contacting each agency depended strongly upon the agency's degree of R&D centralization/decentralization. In every case, however, authorization was given to work through a management level liaison within the agency. It was through

123

the cooperation of this liaison that contact was made with Program Managers. Program Managers were the focal point of the study since it is their day to day decisions which influence the progress of R&D projects.

Prior to contacting Program Managers, background knowledge of which of their projects would be appropriate for inclusion in the study was obtained. This background knowledge, coupled with the ISR staff's orientation towards science and technology, ensured good working relationships with the Program Managers.

Full cooperation with the relevant Program Managers was essential to the successful conduct of the study, for without their aid, access to the appropriate contract files would have been impossible. The availability of contract files was invaluable in the development of complete and accurate project histories for each of the projects included in the database. Such histories along with the cooperation of the Program Managers allowed all project related incentives and barriers to be identified and explained. To insure that the identified events were correct and complete, verification was obtained from the Program Manager.

DATA COLLECTION

Data collection basically entailed a three-step process. *Step One* entailed the use of a semi-structured interview of the relevant Program Manager to obtain a brief description of a project's history to determine whether the project met the selection criteria for inclusions in the study. Such criteria were designed to allow the representation of projects which have been conducted under a variety of R&D conditions. *Step Two* involved the more detailed analysis of those projects which satisfied the referenced selection criteria. This analysis required the inspection of the Program Manager's contract files for the purpose of identification of project specific incentives and barriers. *Step Three* of the data collection process had a twofold purpose. On one hand, the closing interview was used to answer any remaining questions about the R&D project. However, of no less importance was the application, in a structured interview, of the Attributes model. It was through this model that the Program Manager's perception of his project (i.e. its incentives and barriers) were recorded.

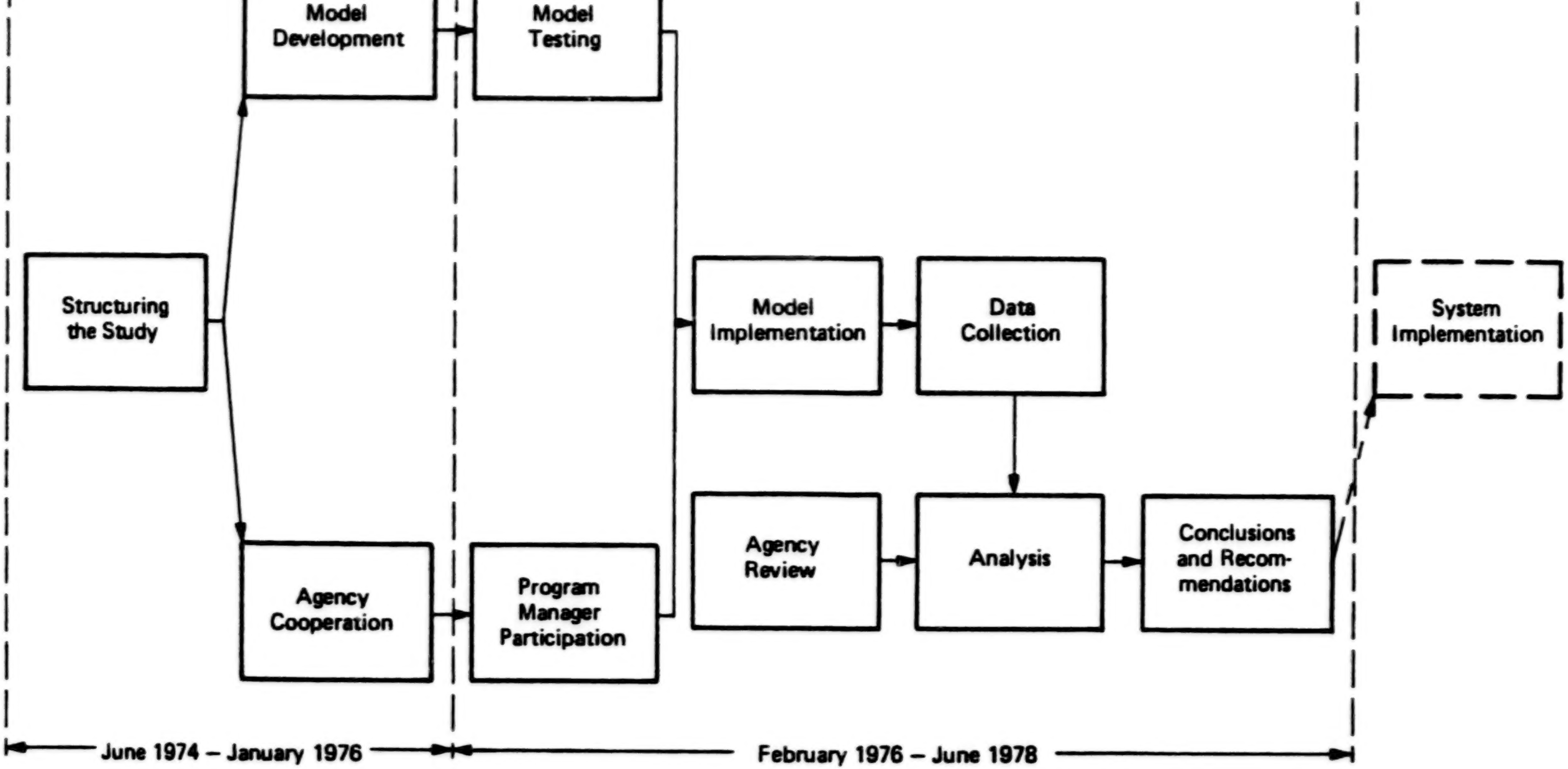


FIGURE 1
APPROACH

BEST DOCUMENT AVAILABLE

MODELS

As noted previously, three models were developed during the course of this study, the *Research and Development Similarity* (RDS) Model, the *Interim Components of Success* (ICS) Model, and the *Attributes* Model. These models along with the specific purpose and application of each is noted in Table 3.

The Research and Development Similarity Model

The RDS Model was originally developed to aid in the selection of R&D projects which could provide a representative sample of the R&D activities funded by the three cooperating Federal agencies.

The initial step in the development of the RDS Model was to isolate the key variables which could accurately reflect similarities among R&D projects. A modified Delphi technique was then used to identify the most important variables. Once these variables were distinguished, additional ranking and exclusion of the least important variables yielded the following ten variables:

- PRODUCT OR PROCESS DESCRIPTOR
  - is the result of the R&D effort expected to provide a product (i.e. a tangible item produced through physical or intellectual labor), or a process (i.e. a series of controlled actions or movements, systematically directed toward a particular result or end)?
- LEVEL
  - does the final product represent a complete system, subsystem, or a component?
- USER
  - is the primary user of the results of the R&D effort the Federal government, a State/local government, a private sector manufacturer, or a consumer (i.e. a private sector end user who is not a manufacturer)?
- STAGE
  - at what point on the DRI* nine stage model of the innovation process does the R&D currently correspond?

---

*Denver Research Institute

- PROJECT BARRIERS
  - what are the most serious impediments to commercial utilization?
- DECISION POINTS
  - what have been the significant events thus far in the life of the R&D project in terms of contract support and project success?
- TIME TO UTILIZATION
  - what is the estimated time (in years) needed to allow utilization by the private sector?
- COMPETING TECHNOLOGIES
  - to what extent are similar projects addressing the same needs or goals?
- TECHNICAL STATE
  - what is the technical nature of the R&D (i.e. advanced vs. state-of-the-art)?
- AGENCY
  - what Federal agency is sponsoring the R&D?

After these ten variables were distinguished, a second iterative process was used to assign weights to each of these variables. A scoring model was then used to calculate a score representative of the degree to which two projects are similar. It should be noted that the RDS Model measures more than mere technological similarity, and that the similarity between two projects is also a function of the types of barriers present, the user of the R&D, the number of competing technologies, as well as the technical state of the R&D.

The Interim Components of Success Model

The ICS Model was developed as a means toward obtaining an unbiased indicator of a project's progress toward commercial utilization. The model is a scoring model which attempts to indicate the extent to which various project related activities, undertaken or sponsored during the life of the R&D project, can contribute to

BEST DOCUMENT AVAILABLE

MODEL	PURPOSE	APPLICATION
Attributes	Examine characteristics of incentives and barriers	Characterize Program Manager and Contractor perceptions of incentives and barriers
Interim Components of Success	Track projects' progress towards commercial utilization	Assess effect of significant incentives on progress
R & D Similarity	Assess similarity between R & D projects	Sample selection, clustering and comparisons

TABLE 3
MODELS DEVELOPED

that project's ultimate success or failure in terms of utilization. Common examples of such activities include the undertaking of studies or assessments such as market analyses, examination of supporting technologies, technical feasibility studies, and analysis of regulatory and legal impacts. In general, the estimated success of the project increases as each of the appropriate assessments is completed. In terms of weighting for scoring purposes, slightly higher scores are assigned when a particular study is either sponsored by or conducted by a representative of the private sector. In addition, the positive or negative outcome of each study is considered and reflected in the scoring. Along with the observation of these project related studies and assessments, a project's ICS score is also dependent upon the project's ability to avoid cost overruns, slipped progress milestones, and maintain reasonable projections of ultimate costs to the users of the results of the R&D.

In the actual scoring of the model, scores for any particular project can range from a low of zero (i.e. a low estimated probability of success) to a maximum of one (i.e. a very high estimated probability of success). Also since the ICS score may be calculated at various points during the life of an R&D project, comparisons of ICS scores at successive R&D stages can be accomplished. For these reasons, the following estimates can be made with regard to specific R&D projects:

- estimates of project progress toward utilization through inspection of the changes in scores;
- estimates of the "probability of utilization" through inspection of the final score.

The accurate scoring of the ICS Model is seriously dependent upon both access to that project related data which can allow the construction of an accurate project history, and the availability of the responsible Program Manager to verify that history. Such an accurate project history is important to insure the identification of all the above referenced project related activities, as well as all incentive actions taken during the life of the project. In this way, observed instances of incentives being employed, and associated movements in the project's ICS score can be compared to aid in the determination of those incentive actions which are most often associated with greater increases in estimated R&D utilization.

The Attributes Model

The Attributes Model defines each observed incentive and barrier according to a predescribed set of characteristics or "attributes," thus allowing the comparison of various types of incentive actions and barrier conditions. Previously, no means existed to compare, for example, Market and Organizational incentives. To allow such analysis each incentive and barrier observed was rated by the appropriate Program Manager according to the degree to which it exhibited the specific attributes noted in Tables 4 and 5.

The data collection format employed allowed the Program Manager to assign, for each attribute of every incentive and barrier, a value of 1 through 7, dependent upon the extent to which it displayed the specific tabulated characteristics of incentive or barrier.

TABLE 4. ATTRIBUTES USED TO EVALUATE INCENTIVES

- Strength
- Ease of Application
- Cost to Implement
- Impact Upon Time to Utilization
- Impact Upon Cost to Utilization
- Impact Upon Probability of Utilization
- Controllability by Program Manager
- Time Necessary to Implement
- Span of Barriers to Which Incentive is Applicable
- Time Required to Perceive Effects
- Causes Few/Many Unintended Results

TABLE 5. ATTRIBUTES USED TO EVALUATE BARRIERS

- Ease/Difficulty to Overcome
- Time to Overcome
- Ease/Difficulty to Perceive
- Urgency to Overcome
- External/Internal to Federal Agency or Department
- Impact Upon Time to Utilization
- Impact Upon Cost to the Project

Incentive Examples

As noted in the Summary, each incentive action and barrier condition observed was identified as belonging to one of nine types. In the listings provided below, those specific actions which have been grouped under each type of incentive are identified by incentive type.

Economic/Financial

- *arrangement of project funding increases through contract or grant amendment*
- *permitting intraproject transfers of R&D funds*
- *arrangement of advanced payments to contractors*

Legal

- *development of contract specific patent arrangements*
- *use of letter contracts*
- *contract modifications of a legal nature*

Organizational

- *interagency agreements and transfers of funds*
- *establishment of industry/government advisory panels*
- *transfer of contract administration to more suitable subagency office*

Technical

- *government certification of equipment*
- *rent free provision of government equipment and/or facilities*
- *allowance of time extensions for purpose of overcoming technical difficulties*

Information Transfer

- *presentation of project generated papers at an industry conference*
- *"loan" of a specialist to a contractor*
- *requirement that the inventor of the Federally supported technology be consulted in its development*
- *funding of trips to foster the exchange of project related information*

Policy

- *arrangement of grant continuations*
- *allowing a project to proceed prior to budget approval*
- *issuance of sole source contracts*

Market

- *securing project approval from a potential producer of a technology*
- *securing approval of project developed products from the consuming agency*

The single Regulatory incentive observed was the suspension of government regulations which prohibited the testing of several products. No incentives of the Need type were observed in those R&D projects included in the study.

Barrier Examples

Barriers to successful commercial utilization were also grouped according to the nine categories. Specific examples of these barrier conditions are shown under the nine barrier categories listed as follows:

Economic/Financial

- *budget overruns*
- *budget revision difficulties*
- *inflation induced problems*
- *subcontractor difficulties of a financial nature*

Legal

- *need to rebid contracts due to inherent illegalities*
- *inability of contractors to cope with detailed contracting procedures*
- *disputes in regard to patent arrangements*

Organizational

- *delays in subcontract approval*
- *contractor personnel turnover*
- *union difficulties which interfere with work schedule*
- *disputes between prime contractors and subcontractors*

Technical

- *weather problems which interfere with testing*
- *inadequate plans and specifications*
- *supply problems*

Information Transfer

- *poorly written contractor reports*
- *reports which have inadequate or incomplete cost specifications*

Policy

- *reluctance of contractors to proceed without assurances in regard to proprietary rights*
- *difficulties in obtaining testing permits*

Regulatory

- *conflicts with existing government regulations*
- *changes in existing regulations*

Need

- *reduction of project priority*
- *conflicts of opinion with regard to the ability of the newer technology to replace existing technologies*

The single Market barrier observed was the presence of a poorly defined and disaggregated market for the R&D.

By grouping incentive and barrier conditions according to the nine types outlined on previous pages, the Attributes Model estimated the extent to which each incentive and barrier type consistently displayed characteristics or attributes such as those noted. Also the similarity among various types has been estimated through analysis of the degree to which various incentive types consistently display similar characteristics. In addition by grouping incentives according to the R&D conditions under which they were applied, (i.e. many vs. few competing technologies, or advanced vs. state-of-the-art, technical state) those types of incentives which seem to function most advantageously under particular R&D conditions have been identified. These and other results and conclusions of this study are detailed in the following section.

RESULTS - STUDY FINDINGS

In the following discussion the major findings of the study are presented and their significance discussed. Since the results are presented for the most part in terms of various types of incentives and barriers (i.e. Economic/Financial, Technical, Legal, etc.) it is important for the reader to bear in mind those specific examples of actions which are representative of each incentive and barrier type. These examples have been presented in the previous section (Pages 17-20).

The major results of this study have been organized into four general areas. They are:

- *the influence of various types of incentive actions upon project progress by stage of R&D*
- *the characteristics of incentives by type of incentive*
- *the effectiveness of incentives under varying R&D conditions*
- *and the characteristics of barriers by type of barrier*

In this presentation there has been included in several instances, references to two R&D projects, included in the study's database, which have been chosen to illustrate the particular concepts under discussion. These two projects have been selected since one (Project 107) is felt to best demonstrate the selection and use of incentives in such a way that the probability of successful utilization has been enhanced, while the other (Project 204) illustrates the use of those incentives which have been estimated to be less effective in increasing that probability under the circumstances under which the incentives were employed. Where the specific results under discussion can be described in terms of one of these two projects, the example is bounded by verticle lines.

THE INFLUENCE OF INCENTIVE ACTIONS UPON PROJECT PROGRESS BY STAGE OF THE R&D PROCESS

The ICS Model has allowed the estimation of both the progress of any individual R&D project toward utilization, as well as the overall probability of utilization of the R&D results. With regard to project progress, results indicative of the effectiveness of each observed incentive by type and stage of R&D are summarized in Figure 2 and Table 7. Specifically Figure 2 graphically demonstrates the extent to which each type of incentive has been observed to be associated with increases or decreases in the ICS score. It should be noted that while ICS scores can range from a low value of zero to a maximum of one, the values noted in Figure 2 represent changes of scores within these two limits.

Figure 2 was compiled by following the steps outlined below:

1) Each project history was examined and instances of incentive actions being taken were noted

2) The ICS Model was scored at each point in a project's life where an incentive action was observed

3) Changes in ICS scores were observed for the history of the project and the type of incentive action associated with each increase or decrease in score was noted

4) The changes in score were then grouped by incentive type and stage in the R&D process when the incentive was applied to determine the mean score changes as presented in Figure 2.

In assigning specific incentive actions to a particular stage of R&D, the appropriate project history was consulted and each incentive was identified as having been applied during one of the nine stages of R&D as defined by the Denver Research Institute.* For purpose of Figure 2, the grouping of the nine DRI stages is detailed in Table 6.

In several instances only one observation of certain incentive types were noted in particular stages. These single data points are not noted in Figure 2, but are identified by Table 7 where the observed application of all incentives is summarized by stage and ranked by order of corresponding increases in ICS scores. Table 7 also identifies those projects under which the application of the particular incentives were observed.

---

*Federal Incentives for Innovation, Denver Research Institute, prepared under NSF-C680, 1973

136

TABLE 6. GROUPING OF R&D STAGES

Research Definition to Applied Research

1. Research Definition
2. Research Experimentation, Analysis, and Evaluation
3. Product or Process Conception
4. Technical Feasibility Study

Applied Research to Development

5. Technical Initiation (Laboratory Development and Design)
6. Prototype Component and Overall Development and Design

Development to Utilization

7. Pilot Test
8. Preparatory Product and Process Engineering

Utilization

9. Production and Plant Installation

Perhaps the most obvious conclusion to be drawn from the results presented in Figure 2 and Table 7 is that THOSE INCENTIVES APPLIED EARLY IN THE LIFE OF THE R&D PROGRAM (I.E. BETWEEN RESEARCH DEFINITION AND APPLIED RESEARCH) ARE MOST DEFINITELY ASSOCIATED WITH THE GREATEST INCREASES IN ICS SCORES. This fact seems to indicate the existence of a critical period early in the life of the R&D project, during which the application of particular incentives can be most effective in increasing the probability of commercial utilization. Program Managers would therefore be advised to recognize the possibility that those decisions which are made early could be those which will be most significant in the ultimate determination of program success or failure.

Additional conclusions can be drawn with regard to the effectiveness of various specific types of incentives at different R&D stages. Among the more significant conclusions are:

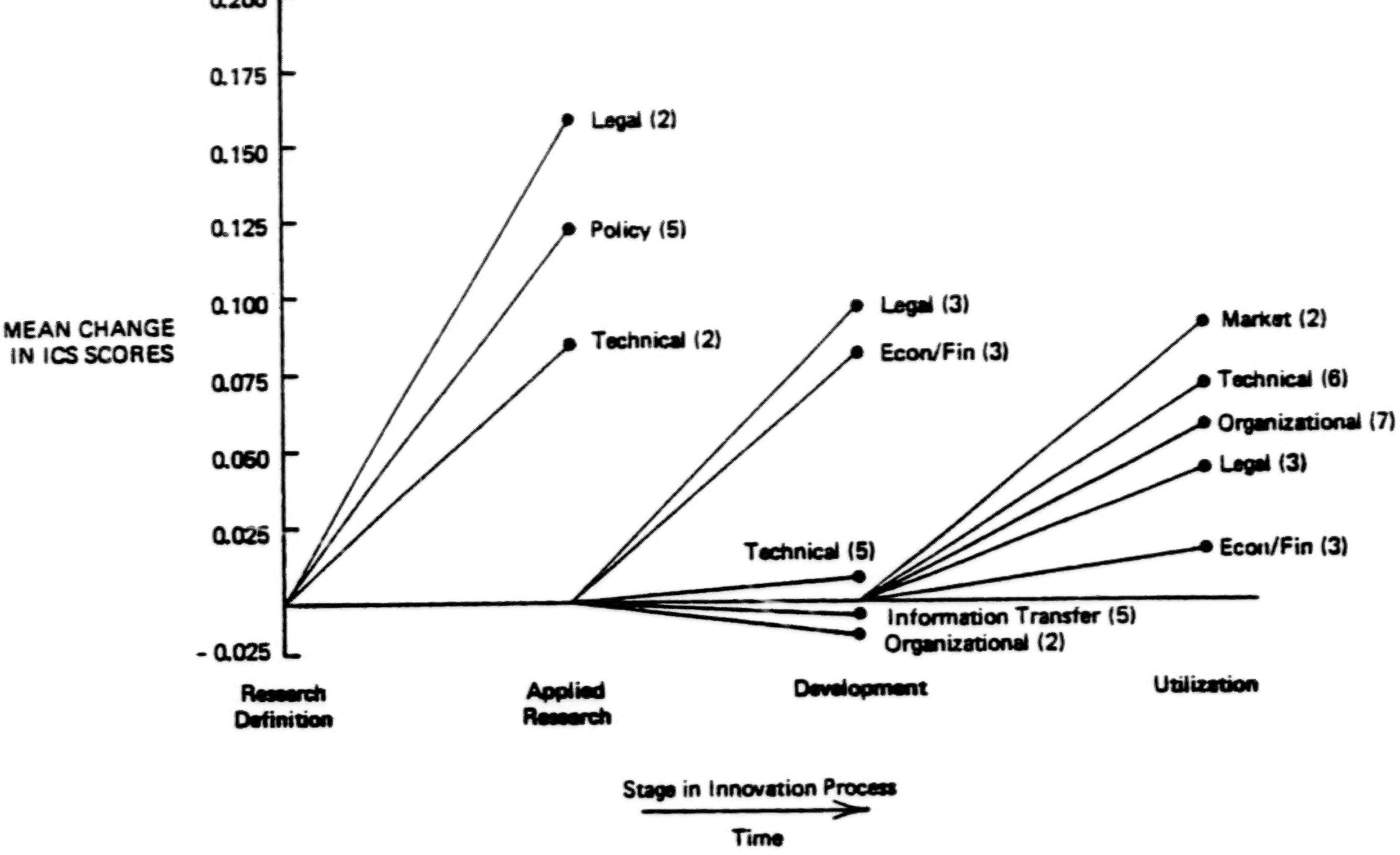


FIGURE 2
EFFECT OF INCENTIVES ON PROJECT DEVELOPMENT
(By type of incentive and innovation stage)

Innovation Stage	Incentive Type	Mean Change in ICS Score	Number of Observations	Projects Observed
Research Definition Applied Research	Legal	0.161	2	104,106
	Regulatory	0.147	1	102
	Info. Trans.	0.147	1	102
	Policy	0.123	5	102(2),106,201,213
	Technical	0.086	2	211,213
	Organizational	0.013	1	103
Applied Research to Development	Legal	0.097	3	102,107,301
	Econ/Fin	0.079	3	108(2),214
	Technical	0.011	5	104(2),202,214(2)
	Info. Trans.	-0.008	5	105,204,210,212,215
	Organizational	-0.019	2	210,301
Development to Utilization	Market	0.089	2	202,203
	Technical	0.073	6	105,205,208,211,215,302
	Organizational	0.055	7	101(2),108,204,205(2),302
	Legal	0.039	3	107,211,215
	Econ/Fin	0.017	3	205,215(2)
	Policy	0.013	1	101
	Info. Trans.	-0.040	1	204

NOTE: Those incentives associated with negative score changes have been judged to be least effective under the stages observed.

TABLE 7
SUMMARY OF MEAN ICS SCORE CHANGES BY STAGE AND PROJECTS OBSERVED

- While Legal incentive actions (contract modifications, patent arrangements) appear to be consistently effective, those applied during the earlier R&D stages seem to be most effective.

- Although no Economic/Financial incentives (advanced payments, funding increases, etc.) were observed to be applied during the period of Research Definition, the effectiveness of this type of incentive seems to diminish as Utilization is approached.

- Organizational incentive actions (interagency agreements, industry/government advisory panels) seem to be both more popular and most effective as Utilization is approached.

- Technical incentive actions (rent free government equipment, time extensions to overcome technical difficulties) are most effective during the Research Definition and Development periods.

- Although Market incentive actions (solicitation of project comment and/or approval from potential producers) were only observed to be applied during the Development period they appear to be very effective.

- Information Transfer incentive actions (presentation of project related papers at industry conferences or requiring consultation by inventor) seem to be relatively weak.

Several observations can be made with regard to the other types of incentives. Specifically, no Need and only one Regulatory incentive was observed to be used in those projects selected for inclusion in the database and subsequent analysis. This is indicative of their infrequent choice as incentives. On the other hand, those which are used most often include those of the Technical, Legal, Organizational and Economic/Financial type.

As noted, two projects included in this study have been selected for the purpose of demonstrating the use of incentive actions at the project level. In this regard, the projects used are Project 107 and Project 204. (Project descriptions of each project included in the study are detailed in Appendix A). Project 107 was selected because the final ICS score calculated estimated that the probability of utilization of the results of the R&D involved was very high, an estimate which was later proved to be accurate since the resulting product (a modified gas turbine) was made commercially available and has since been purchased and used in many instances. Project 204 was selected since the final ICS score calculated ranked relatively low among all other final project scores, thus estimating that the probability of utilization of this R&D may be low.

Inspection of Table 3 shows that two Information Transfer incentives were applied during two stages of Project 204, that is, one during the period of Applied Research and the other during the period of Development. Table 3 also demonstrates that Information Transfer incentives have been estimated to be relatively weak, raising the possibility that the use of alternative incentives may have been more productive. The selection of an alternative in this case is discussed later. With regard to Project 107, Table 3 shows that two relatively strong Legal incentives were used and thus may have been influential in contributing to the ultimate success of this research.

THE CHARACTERISTICS OF INCENTIVES BY TYPE

As noted, each incentive observed to have been applied was rated by each respective Program Manager under the guidlines of the Attributes Model. Data collected has demonstrated that in several instances different types of incentive actions have been observed to exhibit significant variations in the extent to which each incentive type possesses particular attributes. Of the complete list of attributes, (Table 4) the following are noteworthy:

- *the Cost to Implement the Incentive*
- *the Time Required to Perceive the Incentive's Effects*
- *the Ease of Application of the Incentive*
- *the Time Required to Implement the Incentive*

The specific findings are listed below. Where each incentive is noted by type, the reader is referred to the previously presented listing of specific actions which have been grouped by type of incentive. Program Managers can utilize the findings summarized in the selection of incentive actions which have been most often associated with the particular impacts desired.

The Cost to Implement the Incentive

Such costs include those which are directly incurred by the Federal agency or department which has sponsored the R&D effort and do not consider those which may be incurred by the contractor alone. With regard to these costs, the following variations among incentive types have been noted.

- Technical incentives have been identified as being "most costly" to implement followed by Economic/Financial, Policy and Market incentives respectively.

- Information Transfer, Legal and Organizational incentives were noted to be "least costly" to implement.

The Time Required to Perceive the Incentive's Effects

In many cases Program Managers have a need to use incentives whose effects can be perceived immediately or over a relatively short period of time. In this regard, the following variation among incentive types have been noted.

- Legal, Economic/Financial, and Technical types of incentives have been identified as demonstrating their respective impacts over a relatively short period of time.

- Organizational, Market and Information Transfer incentives seem to require relatively longer periods of time before their impacts can be perceived.

The Ease of Application of the Incentive

Another of the characteristics of incentives which has been evaluated by the Attributes Models is their ease of application. Such "ease" has been interpreted as the degree to which the incentive can be implemented by the Program Manager with minimum additional workload on the part of the Program Manager, his supporting staff, or other officials within the department or agency. In this regard the following distinctions have been noted:

- Market, Information Transfer, and Legal types of incentives were observed to be those which can be applied with minimum effort.
- Organizational, Policy and Economic/Financial incentives were noted to be relatively difficult to apply, although these difficulties were not observed to be particularly unmanageable.

The Time Required to Implement the Incentive

With regard to the amount of time needed to implement various incentives, several distinctions have been noted. Such results relate strictly to the time needed to institute the incentive and should not be confused with the previously referenced time to perceive the effects of the incentive. The following distinctions among incentive types have been observed.

- Economic/Financial, Policy, Information Transfer, and Legal incentives were observed to be able to be implemented in relatively short periods of time.
- Organizational, Market, and Technical incentives required relatively more time to be effectively implemented.

The Similarity Among Incentive Types

In addition to defining the characteristics of incentives noted above, the Attributes Model has allowed the various incentive types to be expressed in terms of their similarity to each other. This similarity has been estimated by defining the composite attribute profile for each incentive type and calculating the Spearman Rank correlation coefficient for all possible pairs of incentive types. Those pairs of incentive actions which have been determined to be similar are presented below by order of the strength of their similarity.

- Legal and Technical
- Economic/Financial and Policy
- Information Transfer and Market

By observing the degree of similarity between incentive alternatives, it may be possible for Program Managers to substitute a similar incentive for one which either cannot be implemented or may be suspected to be potentially ineffective. With regard to the previous discussion concerning Project 204, it was noted that in two instances, relatively ineffective Information Transfer incentives were used. Knowing that Market incentives display a high degree of similarity, in terms of all attributes analyzed, and that Market incentives are associated with greater increases in ICS scores (see Figure 2 and Table 7), it is possible that this incentive may have been substituted, thus possibly accelerating the progress of Project 204 toward utilization.

THE EFFECTIVENESS OF INCENTIVES UNDER VARYING R&D CONDITIONS

Previously the effectiveness of various incentive types under different R&D stages (Figure 2, Table 7) was discussed. In this section their estimated effectiveness under varying R&D conditions is detailed. The R&D conditions referred to have been noted in the previous section (i.e. Methods and Models page 12). Those conditions which have been determined to influence the effectiveness of particular incentives include:

- *whether the R&D results in a product or process*
  -(Product or Process Descriptor)

- *whether a competing technology exists*
  -(Competing Technologies)

- *whether the project is an advanced or state-of-the-art (off the shelf) technology.*
  -(Technical State)

This information can be of value to those Program Managers who may be contemplating the use of particular incentives which have been estimated to be more or less effective under varying R&D conditions such as those noted.

In this case "effectiveness" of incentives has been estimated according to the following three measures:

- *the Controllability of the Incentive,*
- *the Impact cf Incentives upon Cost to Utilization and,*
- *the Impact of Incentives upon the Probability of Utiliaation.*

Although all of the characteristics of incentives investigated by the Attributes Model were examined in this regard, only those three noted above showed significant variations in effect when incentives were applied under different R&D conditions.

The Controllability of the Incentive

Controllability has been defined as the level of control which the Program Manager has over the circumstances surrounding the application of the incentive. If the incentive is defined as more controllable than another, the implication is that it can be applied with a minimum of difficulty in terms of attaining second and/or third party approval. The application of Mann-Whitney U tests have demonstrated the following results with regard to incentive controllability.

- Legal and Economic/Financial incentives are less controllable by the Program Manager when applied to state-of-the-art R&D and more controllable when applied to projects which are advanced technologies.

- Policy incentives are more controllable by the Program Manager when applied to projects which have competing technologies and less controllable when applied to projects where no other competing technologies exist.

- Policy incentives are more controllable by the Program Manager when applied to projects which involve a process rather than a physical product.

145

The Impact of Incentives Upon the Cost to Utilization

In some cases the ultimate ability of an incentive to impact the cost to utilization is dependent upon specific R&D conditions. The R&D conditions which have been observed to be relevant in this case are the technical state of the R&D and the existence of competing technologies. Specifically, the following results have been noted.

- Legal incentives are better able to lower costs in projects which are advanced technologies
- Technical incentives are better able to lower costs in projects which are state-of-the-art technologies
- Technical incentives are better able to lower costs of projects with competitive technologies compared with technologies developed in the absence of competition.

The Impact of Incentives Upon the Probability of Utilization

The Attributes Model has allowed some estimates concerning the influence of incentives upon the probability of utilization. However, these estimates are not as sophisticated as those made through the ICS Model in the sense that the impact upon the probability of utilization is not distinguished by R&D stage. According to the Attributes Model the following results have been noted with regard to the influence of incentives upon the probability of utilization.

- Organizational and Technical incentives are better able to increase the probability of utilization when the project is a state-of-the-art technology.

It should be noted that all incentive types were tested to determine possible variation in effectiveness as measured by particular attributes, but significantly different results were found only for those incentive types and conditions noted above. In general, these results suggest that the technical state of the project is an important R&D condition which should be observed by Program Managers when the application of one of the above noted incentives is considered.

THE CHARACTERISTICS OF BARRIERS BY TYPE

Conclusions similar to those noted with regard to the typical characteristics of incentive actions can be made concerning the project barriers which were observed during the course of study. While the complete list of attributes used to evaluate such barriers is provided by Table 5, significant variations have been noted for the following barrier characteristics:

- *the Impact upon Time to Utilization*
- *the Impact upon Cost to the Project*
- *Internal or External to the Federal Agency*
- *the Ease or Difficulty of Perception*
- *the Urgency to Overcome*

Concerning the specific conditions which have been grouped under each type of barrier, the listings presented in the previous section (Pages 17-20) should be consulted. Significant variations in impact for each barrier type have been outlined below. These findings can be helpful to Program Managers in that they can be made aware of the most serious effects of barrier conditions which impact their projects.

The Impact Upon Time to Utilization

Although all barrier types have been noted to impact the projected time to utilization of the results of the R&D, several distinctions have been observed.

- Market, Information Transfer, Organizational and Legal barriers have been observed to cause the most serious delays in time to utilization.
- Regulatory and Economic/Financial barriers were observed to cause less serious delays.

The Impact Upon Cost to the Project

The barriers observed to impact those projects included in the study were seen to impact project cost to varying degrees. Such costs include only those financial burdens which impact the Federal government.

- Information Transfer, Market and Policy types of barriers were observed to have minimum impact upon project costs.

147

- Regulatory and Technical barriers were seen to be those which have the greatest impact upon project costs.

Internal or External to the Federal Agency

Of the barriers observed, several particular types were seen to be typically encountered outside the sponsoring agency or department as well as within its own structure. Specifically, the following distinctions were noted.

- Market and Technical barriers were most often encountered external to the Federal agency while Regulatory, Need, and Legal difficulties were most often observed to exist in the internal structure of the Federal agency or department.

Ease or Difficulty of Perception

Several distinctions were noted with regard to the ease with which a barrier to project progress can be perceived. Such perception is crucial to the successful removal of serious barriers to utilization.

- Policy and Regulatory barriers were noted to be those which are most difficult to perceive.

- Market, Information Transfer, and Economic/Financial barriers were observed to be those which are perceived most easily.

The Urgency to Overcome

Although all project related barriers were observed to be "urgent to overcome," distinctions in this urgency among barrier types were identified.

- Information Transfer, Policy, Organizational and Legal barriers were noted to be the most urgent to overcome.

- Regulatory and Economic/Financial types of barriers were seen to be relatively less urgent to be overcome.

The Similarity Among Barrier Types

Similarity among the various types of barriers observed were estimated in the same way such similarities were drawn among incentive types. In the estimation of these similarities, the total of the characteristics or attributes of each barrier were considered. Spearman Rank correlations were calculated to determine that the following barrier types exhibit similar impacts in terms of all barrier attributes.

- Legal and Organizational
- Economic/Financial and Market
- Need and Organizational

APPENDIX A

PROJECT DESCRIPTIONS

In order to insure the accurate collection of project-specific and often sensitive data, the Program Managers cooperating with this study were assured that their respective projects would remain anonymous. However, so that the readers of this document may determine the degree of similarity between any particular on-going R&D project, and those included in the study described in this document, the following project descriptions are provided.

PROJECT 101

This project resulted in a send/receive terminal designed for use by one segment of the transportation industry. The need for the terminal was brought about by the necessity for communicating weather information to the vehicles. High cost and risk reluctance of union operators to use the equipment, difficulties in arranging for multi-operator field testing and partial funding were the significant barriers on this project. These barriers were, for the most part, overcome. To date, sixty units have been installed with ten of the units being partially subsidized by the Federal government.

PROJECT 102

The purpose of this project was to develop a system for international data communications that can be used by all participating firms in the industry. This system is one module of a much larger system. The total system concept is novel in that the agency is working to set up an industry group that will provide the computer and software support necessary for operation. The system will decrease the costs of international data communications by aggregating all users under one computer telecommunications network. To ensure that the system gets the high level visibility, exposure and interest that is required for successful implementation, the Program Manager contractually required that the user who participated in the first phase, participate in the second phase. At the start of Phase II, there was a slowdown in the project's momentum. This slowdown was attributable to the reluctance of the users to cost share. It appears that the need for cost-efficient communications by the users will eventually contribute to the project's success.

PROJECT 103

The need for this project was prompted by Federal regulations concerning the disposal of sewage. A private sector firm, which was being penalized as a result of its effluent discharge, contacted the Federal Government and proposed a research effort. By the mechanism of interagency transfer of funds, and provision of equipment from another Federal agency, the initial sponsoring agency was able to fund the proposed work effort. Ozone was finally chosen as the disinfecting agent, and a prototype system was designed. Construction of the prototype will be field tested in a facility of the firm which proposed the development.

PROJECT 104

The intent of this project was the development of automated welding equipment which can operate effectively in vertical, horizontal, and off-vertical orientations. Technical problems during development, however, resulted in modifications to the statement of work. The equipment was successfully demonstrated despite a six month delay caused by supply problems. In operation, the equipment is 2.5 - 5 times faster than conventional vertical welding equipment. The welding equipment has been sold at a profit to more than twenty users.

PROJECT 105

The design of this project is to explore alternative applications of laser technology in construction processes involving the cutting and welding of large steel plates. The greatest barrier faced by the proponants of such applications is the high cost of obtaining and maintaining a laser with sufficient power to cut and weld plates of up to four inches in width. This particular barrier was overcome through efforts on the part of the Program Manager to locate and arrange free contractor use of a Navy-owned laser. Such a laser, once provided, proved that high powered welding was indeed feasible, however financial demands continue to inhibit the commercialization of such techniques.

PROJECT 106

The purpose of this project was the development of a computer aided simulator to assist in the training of operators of water-bound cargo carriers. The development of such a simulator was deemed important if the amount of cargo and property damage resulting from collision and other accidents was to be reduced. The greatest barrier to the development of such a system was the complaint that such simulators were in existence, and further development would entail duplication of effort. This barrier was overcome through a shift in project goals, making research the major project objective. Thus, the completed simulator is now aiding the industry through research in collision avoidance, control room design, traffic regulation and harbor design.

PROJECT 107

The goal of this project was to make the necessary modifications in a standard gas turbine power plant, in order to allow its use in an alternative transportation industry. Of particular concern was the reduction of the turbine's size and weight which would allow an equivalent increase in the stock transportable by the carrier. The strongest barrier to acceptance was the reluctance of the domestic industry to demonstrate the modified turbine in commercial applications. This barrier was overcome when the Program Manager authorized the use of the turbine in several non-related transport activities, thus proving the new turbine's viability. The use of the turbine in such non-related applications convinced industry leaders of its "cost-effectiveness" and a growing number of such turbines are now in use.

PROJECT 108

The objective of this research project is the development of a computer controlled method for the cold formforming of metal frames, especially large steel beams. The successful development of such a method could eliminate variations in bends and out-of-plane deformations which demand costly accommodations in the production process. The greatest barrier to commercialization was the fact that agency sponsoring of a full scale model would give an unfair advantage to the relevant firm, thus such a model was judged "impossible to contract." This barrier was overcome through the efforts of the Program Manager to locate a suitable sponsor in another government agency. Such a sponsor was found and the full scale model is currently under production.

PROJECT 201

The program endeavors to develop means to speed the biodegradation of cellulose. This involves using an acid pretreatment of solid waste cellulose products such as paper or wood to degrade the materials into glucose, which can be utilized elsewhere. The program attempts to specify the optimal pressure and temperature parameters to speed the biodegradation. The Program Manager has cited few project specific barriers and has suggested that it is virtually problem free. The objective of the program includes developing the system to the point where waste can be processed continuously rather than in batches (discretely).

PROJECT 202

The primary objective of this project was the development of a system capable of disinfecting parallel streams of effluent from an activated sludge and a trickling filter waste water treatment plant. The major disinfectants were chlorine and ozone. The chlorinated, dechlorinated and ozonated streams, and a control stream of the same effluent were compared for their toxic effect on several species of fish and macroinvertebrates. Several barriers were observed during the completion of the project, including poorly written reports, reduced program priority and the use of unqualified employees. These and other barriers have been overcome and although the project research is continuing, the future of these alternative treatment techniques has not been determined.

PROJECT 203

The objective of this project is to judge the feasibility of treating and disinfecting domestic waste water through the utilization of ultraviolet light. Such techniques had been previously tested and proven successful in the treatment of drinking water. Patent difficulties proved the most serious barriers in the completion of this research, and agency cost review requirements have delayed the full scale testing of such disinfection techniques.

154

PROJECT 204

The intention of this project is to develop alternative treatment techniques for the treatment of domestic wastewater, other than the traditional oxygenation methods. The most significant barrier to utilization was the failure on the part of the contractor to provide cost specific data on the techniques developed during pilot testing. This barrier was eventually overcome when the Program Manager threatened to withhold official publication of the final report. At this stage, plans for a full scale plant, incorporating techniques tested under agency guidance, are being developed.

PROJECT 205

The objective of this research is to develop feasible alternative methods of transporting domestic wastes to sewage treatment facilities. Traditional transport methods involve the utilization of gravity mains and periodic pump units. Such methods are not practical in areas where geographic conditions, in particular hilly or mountainous terrain, prohibit the use of such techniques. The research is exploring the practicality of vacuum and pressure technology, and has been hampered by such barriers as insufficient need, report difficulties, inflation, as well as various technical problems. However, most of these problems have been surmounted and such technologies have been successfully applied and tested in various sections of the nation.

PROJECT 206

The intent of this project is to explore the possible uses of discarded solid wastes in the development of construction building materials. The research proved that building products could be developed from solid wastes and that esthetically pleasing and structurally adequate materials can be produced for little more than half the cost of traditional products. The process of creating such building materials is currently at the marketing stage.

PROJECT 207

The purpose of this project was to develop a suitable solution to the problems resulting from combined storm/sewage wastewater collection facilities, during periods of wet weather. The subsequent research resulted in the design and construction of a device which is capable of: 1) collecting the inflow which would normally by-pass the treatment facility, 2) separating solid from non-solid material, and 3) discharging the treated inflow. Despite legal problems and others resulting from unclear need for such expenditures, the resulting technology is currently being tested in several locations.

PROJECT 208

The mission of this research was to develop a surface preparation coating which would minimize ice and water adhesion to roads. The successful development of such a substance would reduce the need for road salting and thus limit the ecological damage of such salts. Several barriers were encountered during this research, including weather problems, contract difficulties, and publication problems. Despite these difficulties, several preparations have been developed and are currently being tested under varying conditions.

PROJECT 209

The objective of this project is similar to Project 207, in that it is an attempt to avoid the problems resulting from combined sewer overflows. However, in this case the feasibility of maintaining sewage within various mains and interceptors was explored. The resulting research proved that through the application of computer technology such in-line storage provides an attractive alternative to combined sewer overflows. Successful pilot tests have allowed the installation of several systems employing the technology developed by this research.

PROJECT 210

The purpose of this research was to develop a process which would reduce the level of harmful effluent generated by the textile industry. The project resulted in the successful development of a process whereby much of the dye contained within the effluent could be removed, while the high temperature of the remaining effluent is maintained. In addition to the removal of all dyes, the maintenance of such effluent temperature enables recycling of the heat generated. At this point in time, this process has been successfully proven and awaits commercialization.

PROJECT 211

The purpose of this project was to design and build a system capable of removing, treating and returning water which had been fouled as a result of spills of toxic chemicals and/or oil. Several problems hampered the successful completion of this project, including design problems and cost overruns. But the most significant was the lack of actual spill conditions, under which the system could be tested. However, such conditions were eventually encountered, and the system proved able to handle a variety of potentially dangerous situations, and the services of such a process are now available from several private sector contractors.

PROJECT 212

The objective of this project is to develop a handbook incorporating tested and proven procedures in dealing with various pollution problems requiring quick reaction. Perhaps the most significant barrier to the development of such a handbook is the fact that the number of persons and firms that have actual experience in dealing with such problems is very small. The Program Manager has attempted to surmount this barrier by requiring that the contractor should be readily available for site inspection of problems demanding immediate attention, thus acquiring first hand knowledge of which procedures yield the most reliable results. At this time, the pertinent handbook is nearing completion.

PROJECT 213

The purpose of this research is to test, under controlled conditions, the ability of several chemical compounds to minimize the ecological damage caused by spills, through the pre-treatment of shorelines. The compounds to be tested have been developed under separate contracts. Several barriers have been encountered, ranging from cost overruns to administrative difficulties in obtaining permits to spill. However, the most serious problem was the inability to test the compounds under actual spill conditions. To do so would require the storage of compounds in large quantities at various locations. At this point, the surface preparations have been tested on one beach in a spill prone area, but objections to the validity of these tests have been raised.

PROJECT 214

This project was initiated in response to the need to treat human wastes eminating from vessels on inland waterways. Technical problems eliminated one potential solution to such problems which utilized incineration, while the development of other treatment techniques were delayed or postponed as a result of constant changes in regulations. At the current time, the project has been termed a technical success, but its ultimate commercial acceptance cannot be predicted due to the uncertain nature of future regulations.

PROJECT 215

The objective of this research was to develop and test, under actual conditions, the feasibility of a method of detecting and reporting the presence of spilled chemicals in rivers, lakes, and/or streams. Funding of such research resulted in a system which could attain these goals while unmanned. The research resulted in the development of a satisfactory system despite the problems created by inability to move the spill warning device from one test site to another, as well as decreased testing time prior to actual site testing.

PROJECT 301

This project resulted in a pump designed to transfer a hot mineral fluid under severe operating conditions. The project was given initial Federal funding under a grant from the National Science Foundation. After the demonstration was successfully completed, the project was transferred to another Federal agency. The principal barriers to the project's commercial utilization were external to the sponsoring agency, but were overcome through the Program Manager's incentive strategies. Marketing of the product is now being performed by the private sector, and it is expected that the pump will be commercially successful.

PROJECT 302

The R&D under this project resulted in a polymeric material that can be used as a protective liner in a corrosive environment and in construction for several industries. Initially, the Federal government approached one chemical firm who, although currently holding the largest share of the market, did not wish to participate in the research. Another firm was approached, and, desiring to increase their market share, they agreed to work with the agency. The most significant barrier on this project was the lack of technical specifications for the desired material. This barrier was overcome by the Program Manager who, through an interagency agreement, arranged to have the material tested. At last reporting, the agency has let a contract with a potential user of the material. The purpose of the contract is to conduct field tests at two different sites.

PROJECT 303

The purpose of this project is the development of a direct contact heat exchanger. Once fully developed, this heat exchanger will decrease system maintenance costs and work more efficiently with lower temperature energy sources than is possible with conventional heat exchangers. The principal barrier on this project centered around patent rights. Field tests that have been performed appear to corroborate the projected technical and economic viability of the heat exchanger.

PROJECT 304

This project was sponsored for the purpose of creating a materials handbook. The handbook was initially proposed by the private sector as a means for collecting and analyzing data on the characteristics and applications of materials. Need for the handbook was recognized by the difficulty in transferring accurate, consistent information on current developments in materials and their applications. The most significant barrier on the project was the award of a contract in response to the unsolicited proposal. This project is still being performed.

PROJECT 305 & 306

Projects 305 and 306 were competing technologies which were funded as parallel developments by the same agency. The product resulting from the research was a vehicular transmission system that would cut fuel costs by 20% to 25%. Although estimates show that the cost of the transmission will be 20% greater than current costs, it is expected that vehicle owners would be able to recoup their investment in one to two years. One of the prime reasons for Federal and commercial interest in the transmission packages was the possible impact of Federal regulations upon the industry. The true impact of regulations is not known, since the industry is fairly strong and can exert significant pressure. Project 305, which was being performed by a major manufacturer, utilized the traction approach, while Project 306, which was being performed by a small R&D firm, utilized the hydromechanical approach. At the inception of Federal funding, Project 305 was still in the conceptual design phase, while Project 306 was closer to hardware development since it utilizes available technology and components. The primary barriers to development of the transmission packages are cost, industry reluctance and availability of technical data on engine characteristics.

PROJECT 307

The purpose of this project was to develop a portable trailer mounted device for compacting waste glass and metal cans. Such a device can simultaneously provide recycled materials (at a net savings in energy consumption) and decrease the need for sanitary landfills. The manufacturer/inventor had applied for a patent and required funding to demonstrate the system and collect field test data. As a result of the funding, it is expected that marketing will be successfully performed.

PROJECT 308

By applying solid state technology to convert thermal energy into electric energy, this patent-applied-for device could accrue significant savings to its users. The sponsoring agency evaluated the technical and economic feasibility of the device and had funded development work.

PROJECT 309

Project 309 is a piece of equipment which could increase the operating efficiency of lighting devices. The agency, in its technical evaluation, questioned the invention and requested support technical data. If funding is approved for formal testing, and test results are satisfactory, an interagency procurement package may be arranged.

PROJECT 310

The purpose of this project is to decrease energy consumption for space heating. Consumption can be decreased by synchronizing the demands for heating to the time of day. Although the energy saving device was already on the market, the firm required aid in the preparation of a marketing brochure which generically specified the advantages of the device. The device is currently being sold on the commercial market.

BEST DOCUMENT AVAILABLE

SECTION V.

An Analysis of the National Science Foundation's Medical Instrumentation Experiment

This description of the Medical Instrumentation Experiment was prepared by Arthur D. Little, Inc., Cambridge, Massachusetts, for the National Science Foundation. The authors were Philip G. Drew, Ph.D., Patricia A. Gempel, M.B.A., John M. Ketteringham, Ph.D., and Alyce M. Wood. The content is based on various materials provided by the former NSF Program Manager, Evan Anderson, on interviews with all of the industrial participants and others associated with the Experiment. R.M. Colton, currently the NSF Program Manager, has reviewed this report, but all opinions, findings, and conclusions are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Arthur D. Little, Inc.
Acorn Park
Cambridge, Massachusetts 02140

Note: This is a short form of a somewhat longer report, which includes discussion of development of other instruments mentioned in Section II. It is available from NSF or Arthur D. Little, Inc.

BEST DOCUMENT AVAILABLE

An Analysis of the NATIONAL SCIENCE FOUNDATION'S MEDICAL INSTRUMENTATION EXPERIMENT

an effort to accelerate innovations in applications of ultrasonic imaging in medicine

164

SUMMARY

The National Science Foundation undertook the Medical Instrumentation Experiment to conceive and test several ways by which the federal government might accelerate applications of new technology in medicine. The Experiment focused on ultrasonic imaging devices, which in 1974 were under development in a number of universities and companies, both in the United States and abroad. NSF took three initiatives as part of the Experiment: establishment of performance specifications; planning and funding a clinical validation program; and organizing a training program for practitioners.

In February 1974 the NSF announced the Experiment at a meeting attended by representatives of about 100 companies, universities, and government agencies. The companies were invited to join the Experiment by taking up the challenge to develop an instrument meeting specifications announced at that time. Twelve companies signed up.

From this point forward the Experiment diverged from the anticipated plan. It turned out that none of the 12 companies undertook to develop an instrument conforming to the specifications; the plans for clinical evaluation never were announced; and only one training program was funded (and this for only part of its funds). Apparently the Experiment had failed, and yet nearly everyone familiar with it believed that NSF's initiatives had stimulated development of ultrasonic imaging devices.

In evaluating the Experiment we have concluded that the NSF's actions did accelerate development, not by the mechanisms originally envisioned, but by strengthening the hand of proponents and by sharpening competition. When the rate at which commercial competitors entered this field is compared with that for other comparable instruments, ultrasonic imaging, after the Experiment started, is found to be one of the fastest developing. In this sense the Experiment succeeded in finding a way to accelerate transfer of technology to medicine.

Our ultimate conclusion, however, is that the terms of the Experiment are not repeatable, at least not sufficiently so to make into a policy. In ultrasound NSF had spotted a winner, which would have succeeded, though probably not so rapidly, without their initiatives. It is doubtful that NSF (or anyone else) could succeed in consistently picking winners. After one or two failures the credibility and prestige on which the success of the Experiment rested would be spent. Beside this, free market forces work naturally to fill this role. Government can afford to confine itself to actions judged desirable, which would probably not be taken otherwise, such as the traditional roles of support for scientific research land training.

165

TABLE OF CONTENTS

Page

List of Figures and Tables vii

SUMMARY iii

I. INTRODUCTION 1

A. BACKGROUND 1

B. EVOLUTION OF THE EXPERIMENT 2

1. Original Concept 2
2. Specification Review 4
3. Participants 7

II. EVALUATION 9

A. PREMISES OF EVALUATION 9

B. A MODEL FOR COMPARISON 12

C. HISTORIES OF COMPARABLE INSTRUMENTS 15

D. HISTORY OF ULTRASONIC IMAGING 17

E. COMPARISON AND DISCUSSION 33

III. CONCLUSIONS 37

A. CONCLUSIONS ABOUT THE EXPERIMENT 37

B. CONCLUSIONS ABOUT DEVELOPMENT OF MEDICAL INSTRUMENTATION 40

C. CONCLUSIONS ABOUT THE GOVERNMENT'S ROLE 41

166

LIST OF FIGURES AND TABLES

Figure No. Page

1 Behavior of the Model (Plotted with $X_0 = 0.10$) 16
2 Growth of Commercial Activity with CT Scanners 19
3 Growth of Commercial Activity with Gamma Cameras 20
4 Growth of Commercial Activity with Thermographic Imagers 21
5 Growth of Commercial Activity with Automated Blood Chemistry Analyzers 22
6 Growth of Commercial Activity with Centrifugal Blood Chemistry Analyzers 23
7 Growth of Commercial Activity with Echocardiographs (TM-Mode Ultrasonic Devices) 24
8 Growth of Commercial Activity with Ultrasonic Imaging Devices Outside the United States 29
9 Growth of Commercial Activity with Ultrasonic Imaging Devices in the United States 30
10 Growth of Commercial Activity with Ultrasonic Imaging Devices in the United States Before NSF Experiment 31
11 Growth of Commercial Activity with Ultrasonic Imaging Devices in the United States After NSF Experiment was Initiated 32

Table No. Page

1 Summary of Ultrasonic Imaging Devices Produced in the United States in 1978 27
2 Summary of Ultrasonic Imaging Devices Produced Abroad in 1978 28

I. INTRODUCTION

A. BACKGROUND

In 1971 the National Academy of Engineering published "An Assessment of Industrial Activity in the Field of Biomedical Engineering," a report which eventually led the National Science Foundation to undertake Experiment Number 5, the "Medical Instrumentation Experiment" in the Experimental R&D Incentives Program. The premises on which the experiment were based are described in the NAE report and further amplified in the Experimental Plan Summary of the NSF.

The NAE asserted that industrial participation in biomedical engineering was considerably below its potential in terms of what appeared to be technologically feasible and socially desirable, and it sought reasons for this state of affairs. Basically, it said, industry will participate in any new development for which there is reasonable expectation of profit, but in the field of medical instrumentation, profits were often in doubt for a variety of reasons, some apparent and some real. Among these factors was the reality of slow market acceptance of new products and technology in medical applications. The NAE went on to enumerate the presumed reasons for this slowness:

- A lack of communication between technical specialists in industry and medical specialists, making it difficult for industry to ascertain and respond to real medical needs, taking into account, safety, cost, speed, accuracy, personnel requirements, and the nature of alternatives.
- The re-education which may be necessary to use new technology.
- The lengthy procedure (i.e., clinical trials) through which a new product must pass in order to be accepted in medical practice.

At about the same time the National Science Foundation established an Office of Experimental R&D Incentives with the purpose of providing experimental evidence concerning incentives which the federal government might use to increase use of technology in the civil sector. There were six experiments defined at the time, and one of them took the NAE report as its starting point, Experiment Number 5 on Medical Instrumentation.* In 1972 John Maniello, Vice President for Operations of CBS Laboratories, called to the attention of NSF the fact that organizations in several foreign countries were actively engaged in com-

---

* The other five experiments were called (1) Federal Laboratory Verification, (2) Cooperative Research, (3) Innovation Centers, (4) Urban Technology, and (6) Federal Applications.

168

mercialization of important new ultrasonic diagnostic instruments capable of providing high quality images of internal organs. Eventually such instruments became the subject of the Medical Instrumentation Experiment.

B. EVOLUTION OF THE EXPERIMENT

1. Original Concept

a. The Goal

As originally conceived the Medical Instrumentation was intended to test the hypothesis that the federal government could accelerate development of ultrasonic imaging devices by providing certain incentives to U.S. industry. The goal, of course, was not better imaging devices, though these would be a product of the program, but better ways of accelerating applications of new technology in medicine and perhaps other fields as well.

b. Survey Team

In 1973 NSF commissioned a Survey Team, chaired by John Maniello, to survey worldwide developments in ultrasonic imaging applicable to medicine, to develop a specification for a second-generation instrument which could presumably be built within two years, to describe a training program, and to prepare a research and development program. In the middle of that year the Survey Team reported verbally to NSF, confirming the supposition that developments in ultrasonic imaging were proceeding rapidly abroad and that improved devices were technologically feasible. NSF faced the question of what kind of incentives to provide in order to stimulate U.S. industry and accelerate development of ultrasonic imaging devices. They considered but ultimately discarded two kinds of prizes, a cash prize and a guaranteed procurement.

The cash prize, to be awarded to the first individual or group which produced a device meeting formal performance specifications, has worked well in several historical instances, but suffered from the drawback that the runners-up, even if they had superior products, would receive nothing. It was felt that industrial participants would find these terms too risky and would not compete. The guaranteed procurement envisioned purchase by the government of a number of instruments meeting the performance specifications. The Request for Proposals to furnish these instruments would be issued ten days after the first contestant had met the specifications. Thus the winner of the contest to develop the equipment would have the best shot at the procurement but other contestants only a short distance behind would have an almost equally good shot and might win if they had a superior instrument. Eventually, however, this plan ran afoul of government procurement practices and other objections and was abandoned.

169

c. NSF Actions

Thus, the experiment announced in November 1973 contained three actions by the Government intended to stimulate development of ultrasonic imaging devices by U.S. industry:

- establishment of performance specifications written under the auspices of the Survey team;
- planning and funding a clinical validation program to be administered by the Veterans Administration over a period of two years;
- organizing a training program during the R&D phase.

The NSF committed $3 million to this experiment.

Besides these elements of the experiment itself, the Survey Team made several other recommendations.

- establishment of a tissue signature library,
- a "synchronized" research program,
- support of programs to promote exchange of information.

All of these recommendations were followed to one degree or another by NSF.

d. VA Involvement

Because the Veterans Administration operated many hospitals and members of its permanent medical staff were familiar with clinical trials, the NSF signed an Interagency Agreement with the VA in November 1973. This agreement stipulated that the VA would:

- provide facilities and procedures for clinical evaluation,
- prepare an atlas relating ultrasonic images to cross-sectional anatomy,
- develop findings comparing ultrasonic imaging with other diagnostic methods,
- maintain relations between the validation staff of the VA and industrial participants, and
- inaugurate tutorial presentations on use of ultrasonic equipment for the VA, industry, and others.

Nothing was in the agreement about training programs, though ultimately these were the only activities actually carried out with support from the VA.

170

e. Evaluation of the Experiment

In the original concept of the Experiment it was believed that medical instruments went through a series of states from research to maturity as follows:

- research,
- preliminary development,
- final development,
- clinical trials,
- diffusion,
- maturity.

It was hypothesized that the intervals for final development, clinical trials, and diffusion into widespread use would be shortened by NSF's initiatives, namely:

- writing specifications,
- arranging for clinical trials,
- supporting related research, and
- training physicians and technicians in the technique.

It was imagined that the impact of the Experiment could be discerned by comparing the three intervals for ultrasonic imaging devices with the same intervals for other medical devices whose histories would provide baseline data.

NSF issued a request for proposals to carry out this evaluation and in the middle of 1974 a contract was awarded to Arthur D. Little, Inc. The work accomplished under this contract is the principal subject of this report.

2. Specification Review

In accordance with plan the NSF held a Specification Review Conference in Washington on February 28, 1974. Representatives from about 100 institutions — government agencies, universities, professional groups, and private firms — attended. The number of people attending was in itself an indication of the interest which the Medical Instrumentation Experiment had created. As it turned out, this meeting and the activities which led up to it were probably the principal impetus given by NSF to the development of ultrasonic imaging devices.

At this meeting members of NSF, the VA, and the Survey Team explained the concept of the Experiment as it had eventually taken form, reviewed the target specification, and discussed the conditions of participation. Potential participants were given two weeks to comment on the specifications and participation agreement, and the NSF promised to issue final specifications by April 2, and gave participants until April 30 to sign participation agreements; this schedule was maintained.

Potential participants had a number of comments at this conference, many of which led to changes in the specifications. The revised specifications issued on April 2 appeared quite different from those discussed at the meeting, but a careful reading shows that most of the changes were editorial. Industrial participants, recalling the meeting, felt that the experiment was conducted hastily at this stage and that NSF should have listened more carefully to comments and reactions from industry. Among the more important concerns and reservations (we can say now with the benefit of hindsight) voiced at that meeting were these:

- The power level of 0.5 mw/cm² was unnecessarily low. This level had been chosen by the FDA on grounds of safety since it was well under the threshold where tissue damage was known to occur and in the belief that good signal processing could detect returns satisfactorily. Some industrial participants felt that bending over backward to avoid an unproved danger of tissue damage would result in an instrument inferior to what could be accomplished at higher but still safe power levels. At the very least, they felt, the more elaborate signal processing would result in a more expensive instrument.
- The specification was overly restrictive. The authors of the specification agreed that they had had in mind an instrument suitable for imaging organs and other structures in the trunk, excluding the head and limbs, using reflected (not transmitted) ultrasonic signals. They claimed that their specification was suitable for imaging the heart but this was disputed since the imaged volume (a cube 10 cm on a side) was inconsistent in shape and size with the volume which can be imaged when peeking between ribs to insonify the heart. There was a feeling, since borne out by events, that a single instrument suitable for both the heart and other organs might be badly adapted for either and in any case would be more expensive. The specification excluded transmission devices. The revised specification contained language to permit devices specialized for imaging the heart and devices utilizing the transmitted signal rather than the reflected signal.
- Setting a target specification would presumably lead to many companies offering nearly identical instruments, a circumstance which in the normal course of business each

172

company would try to avoid. As a rule, each company tries to distinguish its product on the basis of capability, quality, or price. If many companies had nearly identical instruments, price would be the only remaining variable and such nose-to-nose competition would very likely threaten survival of some companies. Also, if it should turn out, as many of the industrial participants believed, that the specifications did not accurately gauge medical need and technical feasibility, then all the companies producing such an instrument would have a white elephant on their hands. Thus, from their point of view, adhering to immutable specifications to produce what would be a me-too instrument was an unusually risky undertaking.

- The incentive of clinical trials by the VA offered little benefit and some substantial penalties to potential participants. While newcomers to the medical field may have difficulty finding clinicians with whom to work (as suggested by the NAE), established companies have little trouble getting their devices tested. Thus, many potential participants, particularly the very companies already working in ultrasonic imaging devices, who were already front-runners in the competition, saw no incentive. Worse, there were risks. If an instrument were submitted prematurely, or if it were only partially successful, or if something went wrong in a more or less public competition, it might suffer an undeserved loss of reputation from which it would never recover. The VA had no particular qualifications, and, although there were plans to train VA physicians and technicians, other hospitals and teaching centers had highly qualified and prestigious staff. The details of the clinical validation program had not been described (and in fact never were) and this in itself appeared as a substantial and unnecessary risk to many potential participants.
- There were in fact some genuine incompatibilities or at least marginally feasible requirements among the specifications. One concerned the combination of resolution, imaged volume, and frame rate. To resolve two targets spaced 1.5 mm apart over a field 10 cm wide would require about 250 lines. If each pulse must travel 100 cm (a reasonable distance for travel and return to a point in the abdomen, taking account of the necessary setback to permit insonification of a cube), the total scan time is about 0.17 second, which is inconsistent with a frame rate of 15 images per second required (30 desired). Another con-

> cerned the combination of power level, dynamic range of gray scale (60 db), and beamwidth. The very narrow beamwidth was calculated to have sidelobes at about −40 db, which is inconsistent with the gray scale range. Possibly these apparently conflicting requirements could have been reconciled by some ingenious beam-forming, pulse coding, or signal processing, but to the potential participants they seemed unrealistic and from certain points of view unnecessary. Furthermore, because of the brisk pace set by NSF for conducting the experiment, participants felt that there was no chance to explore adequately alternatives to the target specifications and felt that NSF was not really prepared to listen seriously to their concerns (despite repeated asseverations otherwise from NSF).

The specifications were revised on the schedule which had been announced but as remarked above, the revisions were chiefly editorial and did little to dispel the concerns just mentioned. Of course, some of these concerns could not be eliminated; they were essential aspects of the experiment. Others might have been reduced or eliminated, but they reflected various judgments — some medical, some technical, some economic — on which reasonable men might disagree, and it is unsurprising that not everyone saw eye to eye.

3. Participants

At the meeting NSF emphasized the fact that the participation agreement really bound the companies signing it to very little: they did not have to develop an instrument meeting the specifications, they did not have to submit it for tests, and they could drop out at any time. They would be obliged to submit certain financial data but these would be held in confidence by a third party, Price Waterhouse. On the other hand, not signing by the deadline permanently excluded potential participants. The agreement was actually more a contract binding the government to carry out the actions promised as parts of the Medical Instrumentation Experiment.

Eventually, 12 companies signed participation agreements:

- Actron Industries (of McDonnell Douglas)
- American Optical
- Baird Atomic
- Beckman Instruments
- Diagnostic Electronics Corporation
- Grumman Health Systems
- Litton Medical Products

- Picker Corporation
- RCA
- Rohe Scientific
- Smith Kline Instruments
- Unirad Corporation

Looking back on this time, representatives of these companies almost all assert that they joined the experiment without any serious intent to develop the instrument specified. They agreed with NSF that they had little to lose by signing up and because of the permanent exclusion might miss out on something important by not signing up.

In point of fact, the Experiment ended here, though this was not apparent for some time. All the companies but one submitted financial data, but in light of subsequent developments nothing was ever done with this information. The VA never announced details of the validation program. One group under the direction of Dr. Barry Goldberg at the University of Pennsylvania did receive grants from the VA, using money given it by NSF, to train VA physicians in the techniques and interpretation of ultrasound. In August 1976 seven of the companies listed above formally withdrew from the experiment and subsequently four more did so leaving only Diagnostic Electronics Corporation, which indicated unofficially no further interest. The conditions of the participation agreement stipulated that if no instruments were received by April 30, 1978, the experiment would be cancelled, and so it was.

II. EVALUATION

A. PREMISES OF EVALUATION

Following the concept of the Experiment and its evaluation described above, Arthur D. Little, Inc. in 1974 set about collecting baseline data — that is, assembling histories of development of other comparable medical instruments. We had recognized that defining comparability would be a thorny problem, but there seemed to be a number of other instruments which could be regarded as comparable in terms of technological sophistication, cost, scope of applicability, and characteristics of the purchaser. With these criteria in mind we enumerated other instruments from which to choose specific histories for the baseline comparison. These were:

(1) CT (computerized tomographic) scanners,
(2) nuclear scintillation cameras,
(3) thermographs,
(4) automated blood chemistry analyzers,
(5) centrifugal blood chemistry analyzers,
(6) echocardiographs (TM-mode ultrasound devices),
(7) tactile display readers (for the blind),
(8) hemodialyzers (for treating uremia),
(9) cardiac pacemakers,
(10) ocular tonometers,
(11) electroencephalographs (EEG),
(12) electrocardiographs (ECG)
(13) heart-lung machines (for blood oxygenation during open-heart surgery),
(14) membrane oxygenators,
(15) automated differential cell counters,
(16) lung function analyzers,
(17) computerized ECG analyzers,
(18) on-line blood gas analyzers,
(19) fetal monitors, and
(20) panoramic dental X-ray machines.

Needless to say, it is easy to question on one basis or another whether development of these instruments could be regarded as comparable to

176

ultrasonic imaging, but we thought that it would be possible to identify points of noncomparability and make appropriate corrections. After some discussion with NSF we picked the first seven instruments on the list above as subjects for the so-called baseline studies.

At the same time we undertook to follow carefully the development of ultrasonic imaging devices both in the United States and abroad by attending meetings of the American Institute for Ultrasound in Medicine and the World Federation for Ultrasound in Medicine and Biology, by attending meetings concerned with other aspects of medical imaging, following the literature in these fields and by talking with academicians and business persons involved in medical ultrasound.

However, during the two-year period from initiation of the Experiment to August 1976 it became clear that events were not following the scenario anticipated in the concept of the Experiment. At that time seven companies who had signed up for the Experiment dropped out, and as is now known, no one was even trying to produce an instrument meeting the specifications.* The VA had not devised plans for clinical trials, and never did do so. No training had been completed, though the VA had contributed support to the program at Thomas Jefferson University in Philadelphia.** On the face of it, the Experiment had failed. On the other hand, ultrasonic imaging was proving to be a vigorous technology, and participants in the field nearly all felt that the Experiment had had some effect.

By this time, too, we had completed some of the baseline studies and had recognized the difficulties in carrying out the original evaluation procedure. Viewing the Experiment in classical terms, the three intervals would be regarded as dependent variables (outcomes). The four NSF initiatives — writing specifications, arranging trials, supporting research, and training practitioners — would be regarded as independent variables (inputs) whose manipulation was hypothesized to affect the outcome. In the laboratory one seeks to hold all other experimental conditions constant, but in social experiments, such as this one, this is usually impossible, and these uncontrolled variables also affect the outcomes and confound the results. In the Medical Instrumentation Experi-

---

* Dr. William Glenn, formerly of CBS Laboratories and a member of the Survey Team, and currently a member of the faculty of the New York Institute of Technology, did participate in a program to develop an instrument meeting the specifications, though not as part of the Experiment.

** Although they received no support from the VA or NSF, a number of teaching programs are now offered for physicians and technicians at Colorado University Medical Center; Bowman-Gray School of Medicine, Winston-Salem; Duke University, Durham, N.C.; and others.

177

ment, when we compare the development of ultrasonic imaging with other devices, we find the results confounded by at least the following uncontrolled variables:

- extent of medical need,
- novelty of medical application,
- amount of training necessary to operate,
- existence of an associated diagnosis or therapy,
- perceived potential danger,
- technical complexity,
- competing technologies,
- costs to develop,
- costs to purchase and operate,
- regulatory effects, and
- availability of reimbursement.

Since these factors affect times for final development, clinical trials, and diffusion,*** one must make corrections for them in making any comparison. Making corrections for so many factors is difficult, in some cases almost impossible, and in any case is likely to be unconvincing and controversial. In this respect the original approach seemed unworkable.

On the other hand, it is the consensus of most persons in the field acquainted with the Experiment that the NSF's activities actually did accelerate development of ultrasonic imaging devices, though not by the mechanisms originally envisioned. One can argue that the specifications had no effect because no one followed them; the offer of clinical trials had no effect because none were conducted; the training programs funded by the VA had little effect because only a small number of doctors were trained and they were confined to the VA; the associated research had little effect because most of it did not bear fruit during the Experiment. While all these arguments may be true, it still seems that NSF's activities provided stimulus to the field, by strengthening the case for proponents of development of ultrasonic imaging in the United States. From this point of view the historic analogs of NSF's activities in ultrasound are significant commitments of other companies or agencies beyond the original development group. This became the focus of our evaluation.

As the Survey Team noted in 1973 the principles of ultrasound were well-known in the United States, but they believed that most of the

---

*** Not all factors affect all three intervals, and sometimes the effect is direct and other times indirect. For example, technical complexity would directly lengthen time for final development; perceived potential danger would directly lengthen time for clinical trials; and high purchase costs would lengthen time for diffusion. On the other hand, high purchase costs might also indirectly hinder development by casting doubt on commercial viability, necessitating market studies, etc.

development of imaging devices was going on abroad, notably in Holland and Australia where B-scan units had been developed. By the time that the Experiment was announced a number of U.S. firms had committed efforts to development of devices exploiting ideas which would improve the quality of the images, such as:

- better focussed beams,
- automatic steering,
- rapid scans,
- gray scale,
- more sophisticated signal processing,
- digital storage permitting various manipulations of results,
- range gating,
- doppler detection, and
- others.

Thus, the first generation had been developed and marketed, and the Experiment commenced at a time when a number of U.S. companies had already embarked on the many improvements which would characterize the second generation.

As historical patterns of technical developments show, this is the typical course followed. One group (or sometimes more) develops the original idea and markets it. Virtually never do other entrepreneurs simply copy the original idea, frequently because of patents but also because being second with the same device is a weak competitive position. Therefore, the second generation always entails improvements, and seldom do all participants seek the same improvements. In fact, as we have remarked, they generally try to avoid being similar to their competitors and hope that they have hit on a combination which the marketplace will prefer. This was probably the essential factor overlooked in the conception of writing target specifications.

B. A MODEL FOR COMPARISON

Having recognized that NSF's activities acted chiefly to strengthen the hand of proponents of the field and to make vivid the extent of the competition, one sees that the task of comparison should focus on proponents.

Who are the proponents and how can they be counted? We argue that the proponents worth counting for our purposes are the companies which have made a sustained commitment to the field. Such firms reflect individuals who are sufficiently convinced to spend substantial amounts of money acting on their beliefs, sufficiently tenacious to carry through their beliefs, and sufficiently competent to bring their beliefs to fruition.

Focussing our attention on these companies, we face the question of how many such companies the field can support. How many companies should be in the field? We argue that for our purposes there should be just as many as there are. After all, the companies in the field have been persuaded to commit their own time and money; their judgment may, of course, ultimately be wrong, but their analysis has probably been as careful, critical, and complete as anyone's is likely to be.

This view is consistent with the NAE's observation that industry will move into any field where there is reasonable prospect of profit (and, we can add, will avoid any field where this prospect is absent). The number of companies which move into a field is the number which make a positive evaluation of their chance of success, given their appraisal of the field generally, their assessment about what they can add in terms of technology or marketing to make their entry a success, and their judgment about the competition. The best way to determine this number is to count the companies in the field.

Another aspect of the vigor of a field is the rate at which it grows. We can speak of growth in the number of instruments sold, but a more relevant measurement in a growing market is growth of the number of companies which recognize the field as promising. To normalize this measure we shall focus on the rate of growth toward the number which ultimately make the commitment. Thus, the process in which we are interested begins when the first instruments developed by the pioneers become available and ends when all the entrants for the next generation have committed themselves. Strictly speaking, of course, it is not possible to say at any time that all the entrants have made their appearance, but, practically speaking, it is not difficult. When a new device makes its appearance it sparks a second generation, and a number of companies enter the competition. After a time, however, there are few new entrants for this round because the race has been going on so long that it would be impossible to catch up. Unless some new technical, medical, or commercial development recycles the field, the industry moves to a mature phase in which a few companies dominate the field, perhaps others occupy special niches, and it is virtually impossible for a newcomer to enter.

We suggest that this description fits the development of ultrasonic imaging devices, and that with suitable choices it fits development of certain other medical instruments as well. For the sake of comparison we shall focus attention on the rate of growth of the number of companies producing second generation devices.

We have argued that NSF's activities acted chiefly to increase this rate. This can be made plausible if one considers how business decisions are made. Among groups of would-be entrepreneurs some person becomes convinced that a new field has commercial merit and that he sees an opportunity. Somebody, perhaps the person himself, or perhaps a manager or speculator, has to spend money to bring the idea along. Gradually the project develops, probably acquiring proponents along the way, but continually having to face doubts about feasibility, costs, market, competiton, etc. This tension between the believers and the doubters is almost always present and is one of the factors which paces development. What the NSF did by its activities was to strengthen the believers and to sharpen the competition, both of which accelerated development.

We now turn our attention to a mathematical formulation of this approach, not with the idea that this will lend precision to what is admittedly a rough description of a complex matter, but to have a quantified basis for comparison to test the hypothesis that NSF's activities accelerated development of ultrasonic imaging. No matter what the numbers show, we will finally have to admit that the results could be attributed to the effect of the uncontrolled variables, some of which reflect the intrinsic merit of the technology. Nevertheless, the fact that ultrasonic imaging has grown faster than almost any other new medical technology tends to support the conclusion that NSF's activities did accelerate development.

Let $y(t)$ be the number of companies which have brought out a second generation device at any given time and let Y be the total number which ultimately bring out a device. Let $x = y/Y$ — that is, $x(t)$ is the fraction of companies which have brought out a device by time t. At the end of this process, $x = 1$. Now we hypothesize that:

$$\dot{x} = ax(1-x)$$

where $\dot{x} = dx/dt$ is the rate at which x changes, and a is the coefficient of proportionality. We shall treat a as the characteristic constant of the process.

The product on the right of the equation has the following interpretation. The factor x is the fraction of companies which have spotted an opportunity and moved to take advantage of it. The factor $1-x$ is the fraction of companies which finally will but have not yet done so. The larger this latter factor the greater the opportunity because there is less competition. On the other hand, individuals who may perceive the opportunity are perhaps unconvinced of their perception unless they see others reaching the same conclusion, and in any case they do not have the spur of competition to move them to commitment. Thus $x(1-x)$ is the fraction of potential participants who are convinced of the opportunity

181

and do not find the field too highly competitive. This could be regarded as perception of a viable commercial opportunity, and it is hypothesized that the rate at which companies commit themselves to take advantage of the opportunity is proportional to the strength of this perception.

The solution to the equation above is:

$$x(t) = \frac{Ae^{at}}{1 + Ae^{at}}$$

where A = 1(Y-1)

This function is plotted in Figure 1.

One reason for choosing this model is that it deals with data which are relatively easy to obtain and quantify, namely, the entrance of new competitors with a product for sale. It avoids trying to deal with attitudes and considerations probably known only to insiders and often inaccurately recalled.

Being a simplified description of complex events, the model should not be regarded as a rigorous description of the actual situation. However, for the purpose of comparison the model does have the merit of putting all developments on a common footing.

C. HISTORIES OF COMPARABLE INSTRUMENTS

It was the goal of our work to evaluate the impact of the Medical Instrumentation Experiment on the development of ultrasonic imaging by comparing the history of this development with histories of similar instruments. In the course of our contract we compiled detailed histories of seven other instrument developments:

- computerized tomographic X-ray (CT scanner),
- nuclear scintillation (gamma) camera,
- thermographic imager,
- automated blood chemistry analyzer,
- centrifugal blood chemistry analyzer,
- echocardiograph,
- tactile display reader (Optacon).

These instruments were chosen for comparison because they share certain features with ultrasonic imagers: they are comparable in terms of technical complexity; there were other methods already in existence of accomplishing the same function; all of them are sufficiently complex to require training to use them effectively; with the exception of Optacon,

182

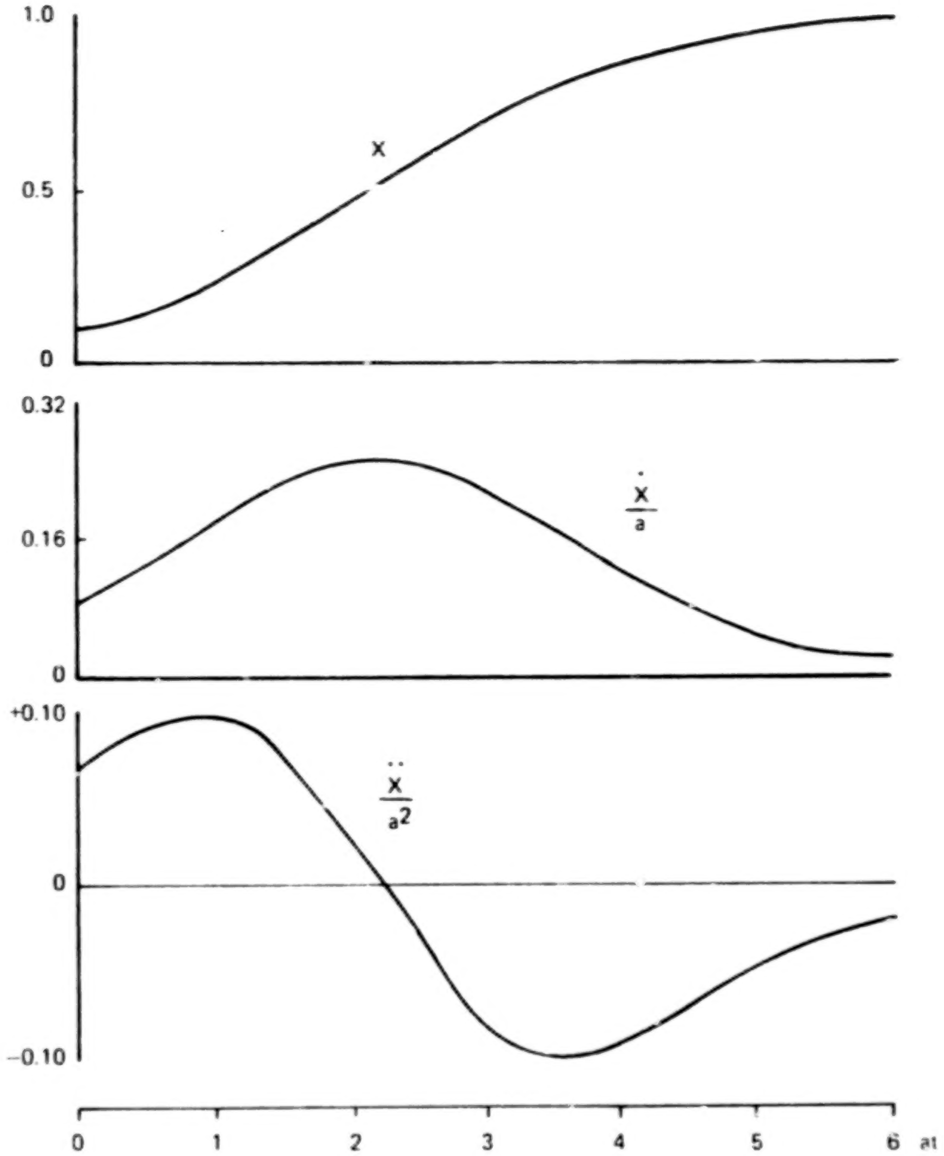


FIGURE 1 BEHAVIOR OF THE MODEL (PLOTTED WITH $X_0 = 0.10$)

BEST DOCUMENT AVAILABLE

they are all diagnostic medical instruments used mainly in hospitals; they can be used for a multiplicity of medical applications; and professional interpretation of results is required.

In order to make use of our model it is necessary to extract from the histories the approximate dates when the original developer introduced his first commercial instrument and when each new entrant arrived with a commercial instrument. Except for Optacon, which attracted no new entrants, this information is shown graphically in Figures 2-7, all of which are arranged in a similar fashion. Each figure shows a period of time during which development of competition was growing following introduction of the first instrument in a class. The ordinate shows growth of competition in terms of the number of companies entering the competition. It is normalized by the number of companies which ultimately enter, as described in the prior section. The dots plotted in these figures are the percent of the number of ultimate entrants as each new competitor enters. The names of the new entrants are indicated alongside the dots.

The curves indicated by triangles in these figures are those obtained from the model when the parameter a has been determined by finding the best (least squares) fit to the data represented by the dots. The parameter a can be thought of as a characteristic growth rate, and its value for each instrument will be a partial basis for comparing developments and assessing the impact of the Experiment.

D. HISTORY OF ULTRASONIC IMAGING

The evolution of ultrasonic diagnostic imaging equipment has followed an irregular path. The basic idea, locating an interface between two inaccessible substances of differing acoustic impedance by measuring the reflections of pulses of high frequency (1-10 megahertz) acoustic waves, had its genesis during World War II, when both radar and sonar, which employ similar principles, were developed. The first patent for a non-destructive testing device using pulse echoes was granted to F.A. Firestone in 1942. In the late 1940s this idea was used to study body tissues by several investigators.

The fundamental idea is to excite a piezoelectric transducer (that is, a piece of a material, such as lead metaniobate or lead zirconate titanate, which deforms when a voltage is applied) so that it emits a short pulse of ultrasonic energy and then to measure the echoes received. Since piezoelectric transducers are bilateral (that is, electrical voltage produces deformation, and deformation produces electrical voltage) the same device can be used both to produce the pulse and to detect its echoes. Whenever the pulse encounters a sharp interface of different acoustic impedance (which can be related to different density or elasticity) some of the energy is reflected and some is transmitted.

Since the speed of propagation of the pulse and its echo is known, one can infer the distance at which a reflection occurred by measuring the time until the echo is received. If the pulse is focussed so that it does not spread out laterally (this is called beamforming), it is like a pencil of energy traveling into the body. The echoes indicate intersections of this pencil with reflective surfaces. One can see that if on a display a line were drawn representing this pencil and if the line were brighter at any point corresponding to the source of an echo, then a lot of these lines side by side would delineate the reflective surfaces. This is the principle of ultrasonic echo imaging.

In the next two decades until the late 1960s, investigators in various companies and universities pursued development of ideas which led to medically useful devices producing cross-sectional images of the body. The important ideas (beyond the fundamental concept outlined above) embodied in some commercial devices today are the following:

- *Automatic measurement* of the position and orientation of the transducer. This enables the device to display the line representing a pencil of ultrasonic energy in the correct position and orientation.
- *Beamforming.* By transmitting the signal from an array of transducers, each of which is driven in precise phase with respect to the others it is possible to cause the pulses from each to reinforce one another in a certain direction and to cancel one another, partially or wholly, in other directions. Thus, the preponderance of acoustic energy goes in a specific direction, and interfering returns from other directions are much diminished. Similar beamforming can be done in detecting the returns.
- *Contact scanning.* Most of the early devices coupled the transducers to the patient by immersing both in water or saline. Others used water bags which press against the patient, and some still do. Many modern devices, however, permit the transducer to be placed directly against the patient's skin, avoiding the cumbersome water bags or water baths.
- *Automatic scanning.* Scanning, that is, aiming the ultrasonic beam, is done manually in some machines where the operator both translates and rotates the transducer (B-scanners) to scan the beam over the two-dimensional slice of interest. (He can, of course, scan adjacent slices to create a set of images which can be said to fill a volume.) In other machines the scanning is done automatically (linear arrays and sector scanners), and this is an essential

185

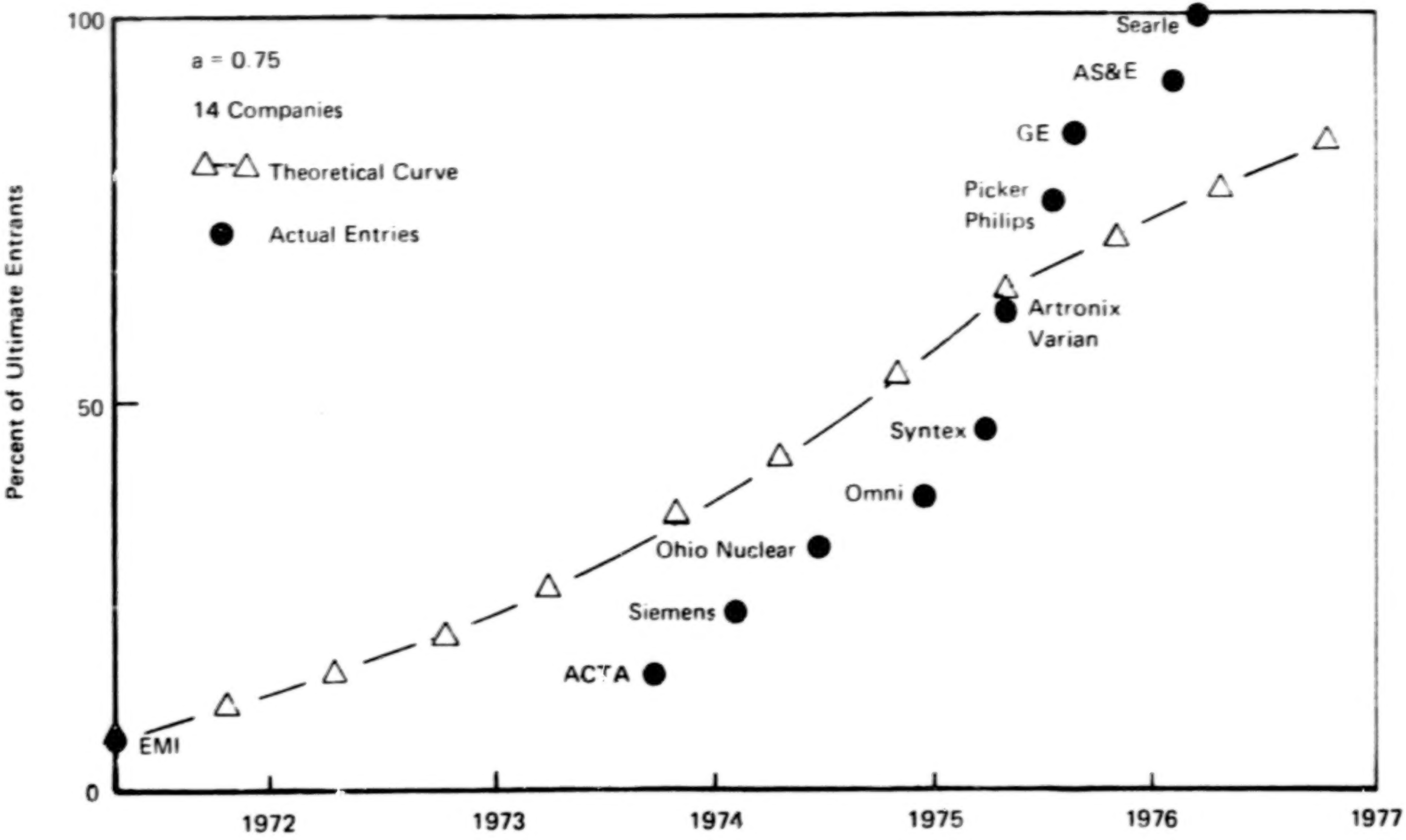


FIGURE 2 GROWTH OF COMMERCIAL ACTIVITY WITH CT SCANNERS

BEST DOCUMENT AVAILABLE

BEST DOCUMENT AVAILABLE

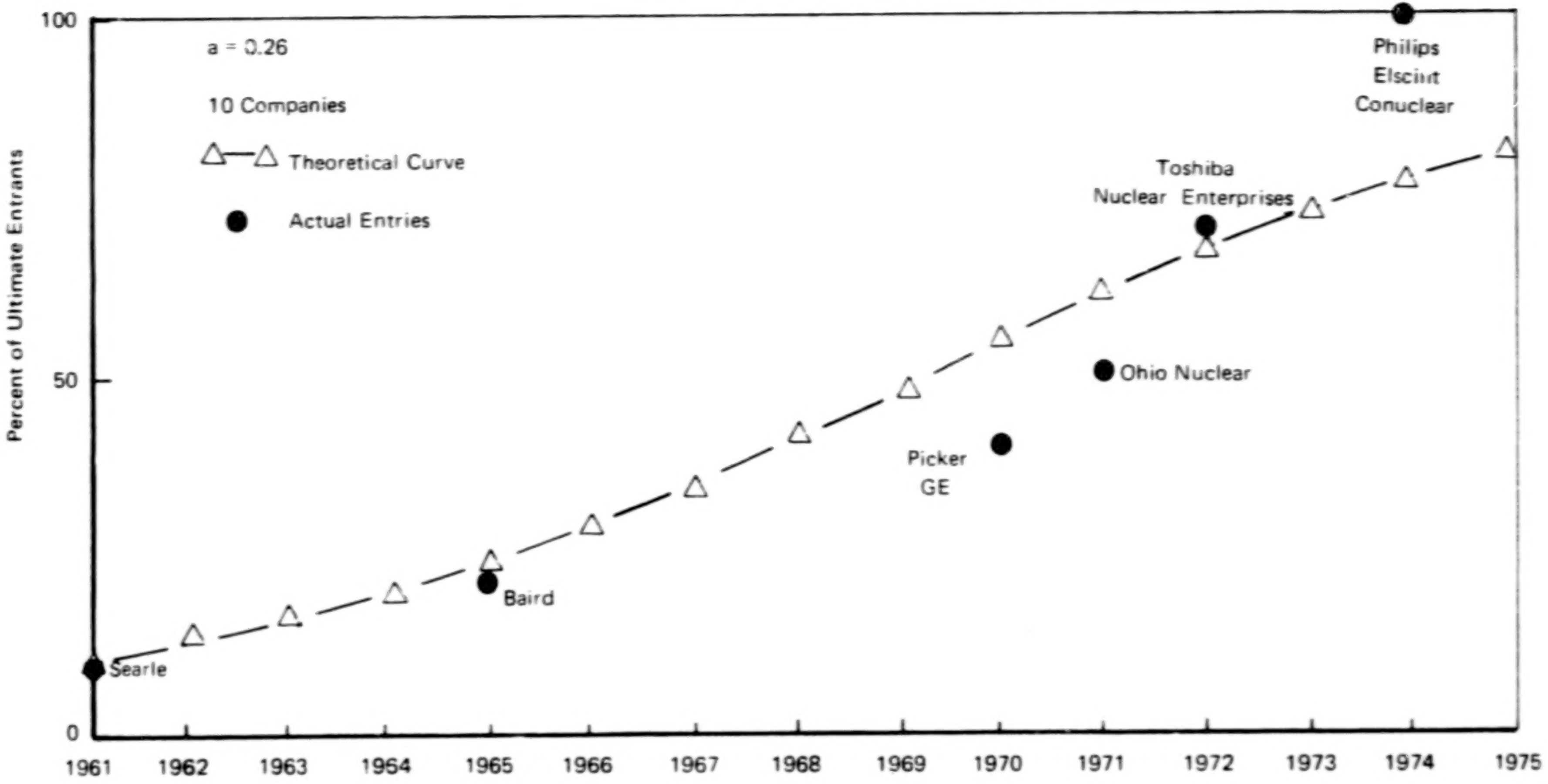


FIGURE 3 GROWTH OF COMMERCIAL ACTIVITY WITH GAMMA CAMERAS

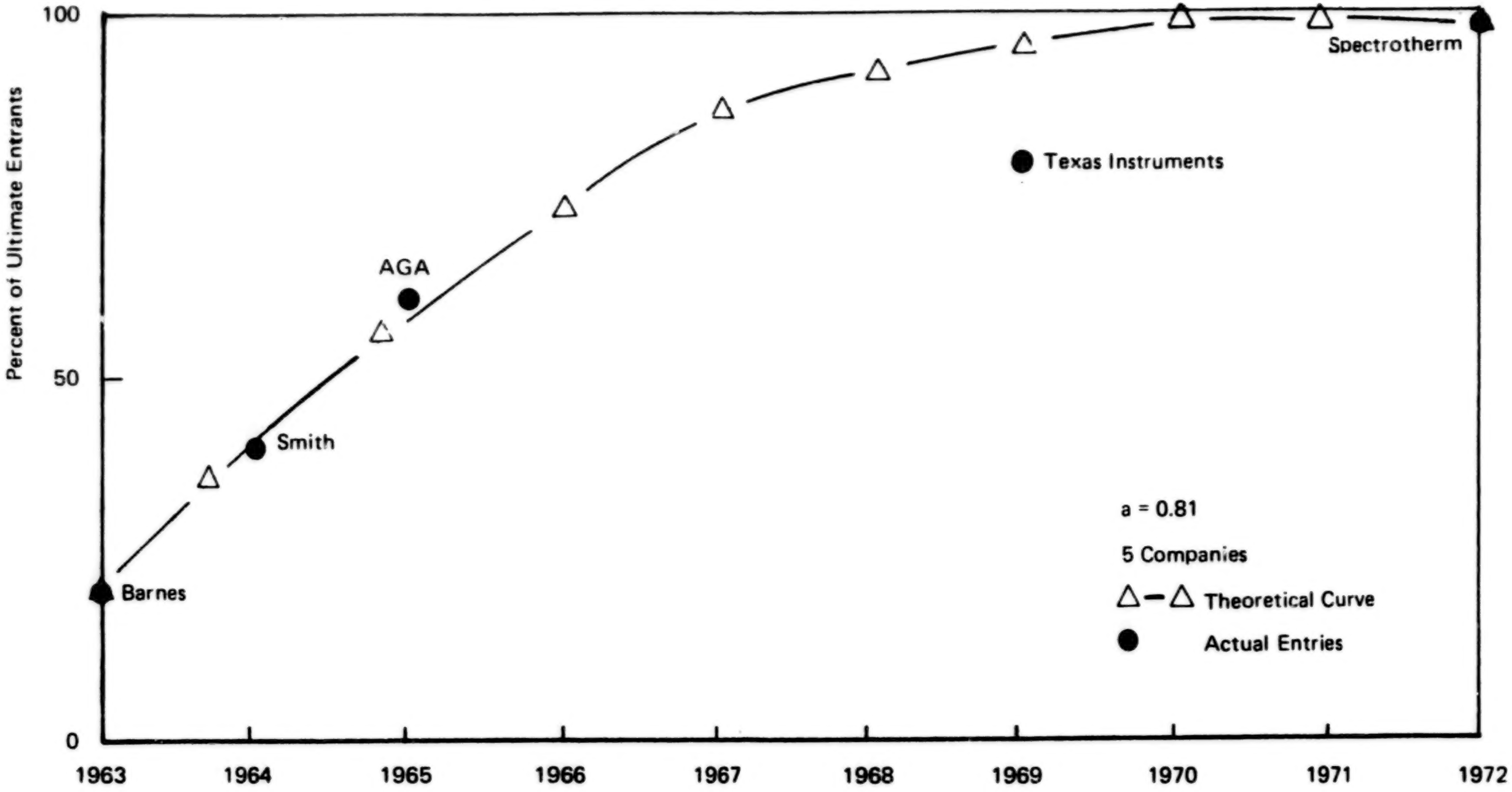


FIGURE 4 GROWTH OF COMMERCIAL ACTIVITY WITH THERMOGRAPHIC IMAGERS

188

BEST DOCUMENT AVAILABLE

BEST DOCUMENT AVAILABLE

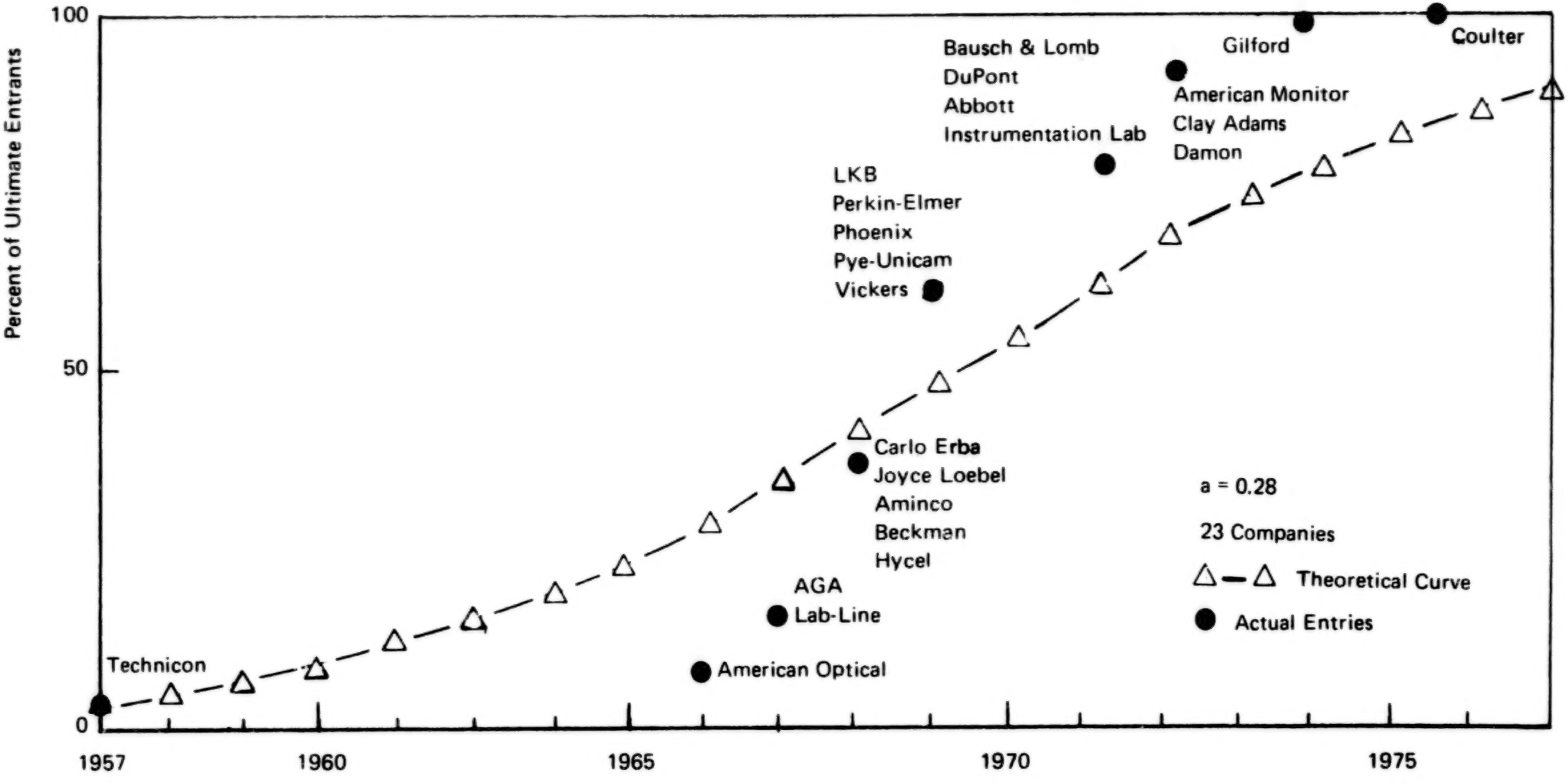


FIGURE 5 GROWTH OF COMMERCIAL ACTIVITY WITH AUTOMATED BLOOD CHEMISTRY ANALYZERS

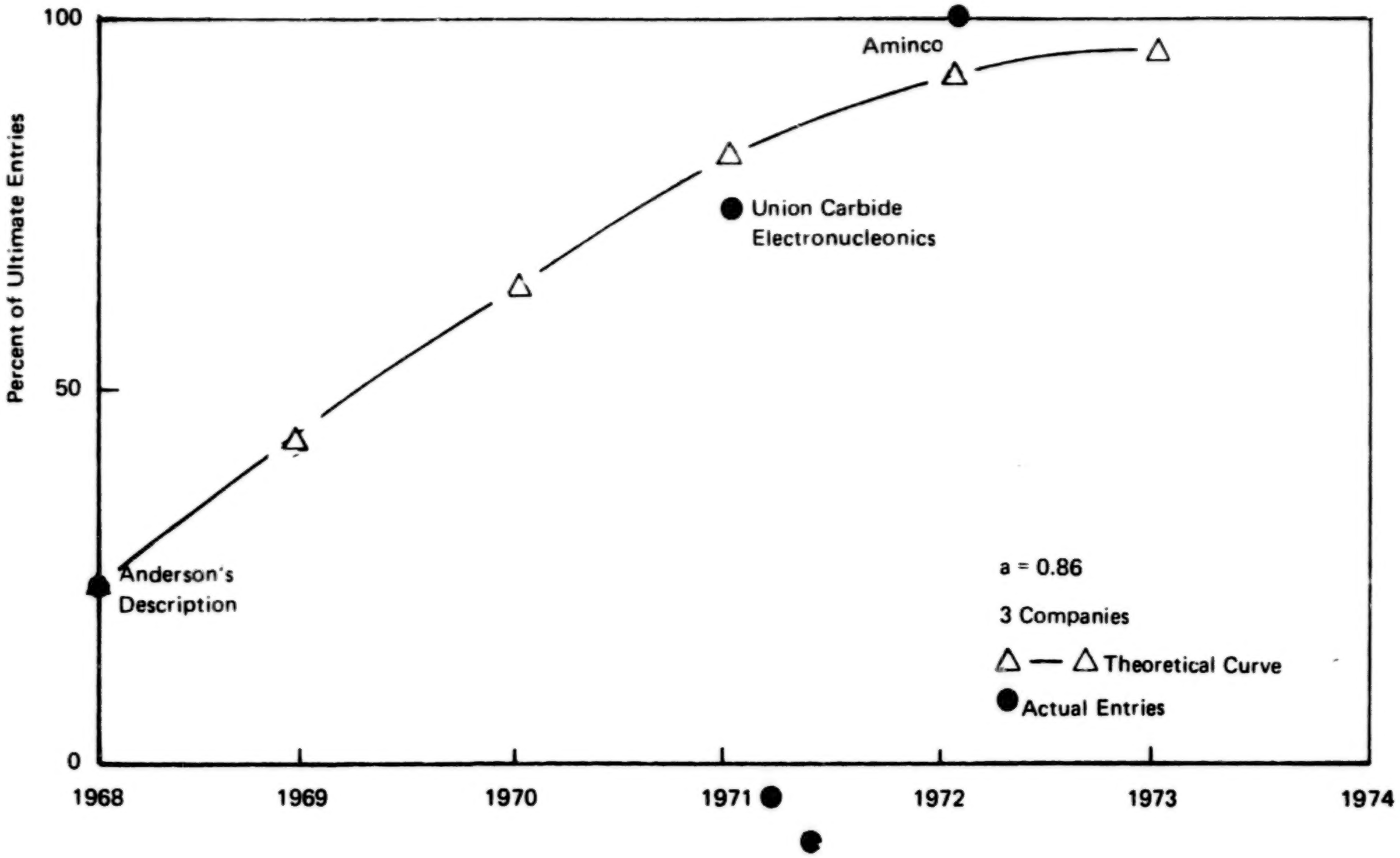


FIGURE 6 GROWTH OF COMMERCIAL ACTIVITY WITH CENTRIFUGAL BLOOD CHEMISTRY ANALYZERS

BEST DOCUMENT AVAILABLE

BEST DOCUMENT AVAILABLE

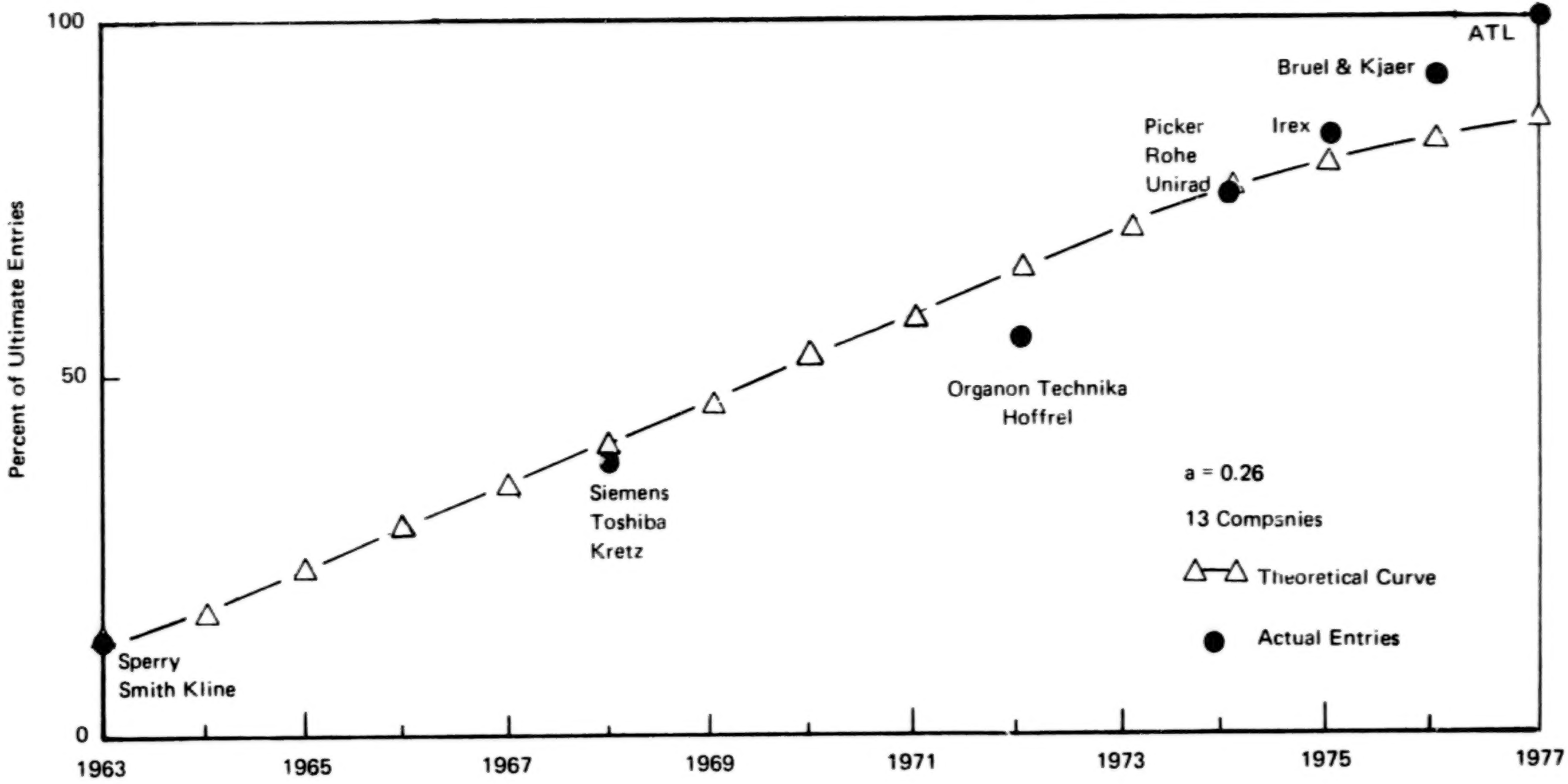


FIGURE 7 GROWTH OF COMMERCIAL ACTIVITY WITH ECHOCARDIOGRAPHS (TM-MODE ULTRASONIC DEVICES)

feature of so-called real-time devices (that is, devices which complete a scan in much less than a second, which is necessary to image rapidly moving structures such as the heart). The scanning may be accomplished mechanically using motors, or it may be accomplished by steering the beam (that is, adjusting the relative phase in an array of transducers).

- *Gray scale.* Early ultrasonic devices produced images which were white where a return had been measured and black elsewhere so that the picture was analogous to a line drawing. Modern devices measure the strength of a return and display a shade of gray proportional to the strength so that the picture is analogous to a charcoal sketch. This refinement, utilizing data which had formerly been discarded, greatly enhanced the diagnostic utility of ultrasonic imaging devices, and it points the direction for further enhancements, namely, measurements of other properties of the returned signal. To varying degrees, different bodily tissues have characteristic properties which affect the scatter, amplitude, frequency, phase, rise time, decay time and other measurable features of the return. There is reason to expect that study will reveal tissue signatures making possible more subtle distinctions than present devices produce.
- *Digital processing.* Early devices used primarily analog circuits for signal processing and for scan conversion (storing the image as it develops at a rate depending on how the transducer is steered and allowing readout of the data at a different rate such as the standard TV frame rate), but modern devices use digital processing. This has various advantages, among them no drift, small size, light weight, high reliability, easy repair, ability to combine alphanumeric data with the imaging data, and recently low cost, but the most significant is reprogrammability to take advantage of new developments in signal processing.

Throughout their development, ultrasonic imaging devices have tended to be specialized for particular medical applications. This observation is still true. It is partly a consequence of medical marketing, where being well-known in one specialty, say cardiology, does almost nothing about being well-known in another, say obstetrics, but more importantly it is a consequence of the special characteristics needed in each medical specialty. Ophthalmology is confined to relatively small volume; cardiology requires a snapshot (a scan completed in 1/15 of a second or less) and must see the heart by peeking between the ribs; obstetrics requires a relatively large imaged volume; etc. While the instruments offered by various manufacturers have diverged to meet these special needs so that not every company in the field of ultrasonic imaging is a direct competitor of every other, they have all built upon a common base of knowledge and experience developed since 1942. For this reason it seems proper to view the entrants in this field collectively, considering those companies which produce an instrument embodying most of the modern features described above.

It can be seen from the discussion above that development of ultrasonic imaging devices was underway both in the United States and abroad well before the Medical Instrumentation Experiment was initiated. A premise at the time was that developments abroad were far ahead of those in the United States. There is some basis for this belief. In 1973, only six U.S. companies (Metrix, Picker, Unirad, Grumman, Rohe, and Sonometrics) manufactured imaging devices, and two of these (Grumman and Sonometrics) were making only small ophthalmological scanners. At that time, however, all of these companies except Picker and Sonometrics were marketing imported equipment, as were Hoffrel and Litton, both of whom subsequently introduced equipment of their own design.

In 1973 there were six foreign companies (Siemens, Kretztechnik, Toshiba, Aloka, Organon Teknika, Alvar) offering ultrasonic imaging equipment, the same number as in the United States. However, it was fair to say that their devices were generally technically superior to those in the United States. It was also true that technical developments were being pursued vigorously abroad, most notably in Australia where Kossoff was pursuing developments which led to Octason, now marketed by Ausonics, and in Holland, where fast scanners, the prototypes for cardiac scanners, were being developed.

By 1979, after the Experiment had ended, there were 17 companies in the United States offering ultrasonic imaging equipment (Table 1) and 18 companies abroad (Table 2). For the purpose of analyzing the rapidity with which ultrasonic imaging developed, the approximate dates on which these companies first entered the market with an imaging device were assembled. They are indicated implicitly in Figure 8, for foreign companies, and Figure 9, for U.S. companies. To focus particularly on effects of the Medical Instrumentation Experiment, introductions by U.S. companies are plotted again in Figure 10 up to 1974 and in Figure 11 for the period after the Experiment was initiated. These figures are constructed in the same manner as the earlier ones.

The growth rate a over the entire period of development was 0.27 for U.S. companies and 0.32 for foreign companies, not much different. The

TABLE 1

SUMMARY OF ULTRASONIC IMAGING DEVICES PRODUCED IN THE UNITED STATES IN 1978

Manufacturer	Manually Scanned Imager (B Scan)	Real-time Linear Scanner	Real-time Mechanical Sector Scanner	Real-time Electronic Sector Scanner	Comments
Advanced Diagnostic Research (ADR), Tempe, Arizona		Real-time Scanner (digital option)			Distributed in Europe by Kranzbuhler in Japan by Asahi Medical
Advanced Technology Laboratories (ATL), Bellevue, Washington			Mark III		Distributed in Europe by Bruno Tonon
Bio-Dynamics, Inc Indianapolis, Indiana		Small Parts Scanner			
Diagnostic Electronics Corp.* Lexington, Massachusetts				Echostat (phased array)	
High Stoy Technology, Inc Bohemia, New York	Bronson B-Scan (small parts)				
Hoffrel Instruments Norwalk, Connecticut			Ultra-Sonoscope Model 201		
Holosonics, Inc Richland, Washington	Acoustiview System 80				Holographic Real-time through transmission system marketed by Kanebo in Japan
Life Instruments Corp Boulder, Colorado		Breast Scanner (3-D display, water immersion)			
Picker Corp.* (CIT Financial) Cleveland, Ohio	System 80L small parts scanner	Linear Scanner 1000		Cardiac Imager	Distributed in Europe by OTE Biomedica
Rohe Scientific* (Philips) Santa Ana, California	Sonodiagnost B-51 (Rohnar 5660 in U.S.) Sonodiagnost B-52 (Rohnar 5680 in U.S. (digital))	Sonodiagnost R			Sonodiagnost R not sold in the United States
Searle Ultrasound Santa Clara, California	Pho Sonic SM	Imager I			Shimadzu markets in Japan
Smith Kline Instruments* Sunnyvale, California		Ekolife		Ekosector I	
Unirad* (Johnson & Johnson) Denver, Colorado	Sonograf EP Sonograf EDP			Sonofluoroscope I	
Varian Associates Palo Alto, California		Echoviderex		SMS Sector (phased array) Model V-3000	Distributed in Europe by CGR
Xerotec, Ltd Frederick, Maryland	Ophthalmic B Scanner				
Xerox Pasadena, California				150 S-4 Real-time Scanner (annular array)	Manufactured by Mediscan, Inc Windsor, Connecticut
Xonics* Des Plaines, Illinois	300/DL Tomographic System				Formerly Litton Medical Medical Products

*Participants in the Experiment

BEST DOCUMENT AVAILABLE

TABLE 2

SUMMARY OF ULTRASONIC IMAGING DEVICES PRODUCED ABROAD IN 1978

Manufacturer	Manually Scanned Image (B Scan)	Real-time Linear Scanner	Real-time Mechanical Sector Scanner	Real-time Electronic Sector Scanner	Comments
Aloka Co. Ltd Tokyo, Japan	Echovision SSD-120	Sonoscan		Phased Array SSD-80°	Echovision produces image in specified plane. Sonoscan marketed in U.S. by Narco-Air Shields
Alvar Electronics Paris, France	Echovar 8		Echovar-8 (optional addition)		
Ausonics Australia Milwaukee, Wisconsin				Octason (8 transducer water path array)	To be marketed in Japan by Asahi Medical
Bruel and Kjaer Naerum, Denmark	Gray-scale System Type 3401	D-scan System 3403	Revolving Transducer System Type 3402		Also manufacture acoustic instruments
Diagnostic Sonar, Ltd Livingston, Scotland		System 85			
Dubernard Hospital, S.A Paris, France		Holoscan			U.S. rights belong to General Electric
General Electric Company Medical Equipment, Ltd Middlesex, England		Telescan 80 (also RITA, an add-on linear array)			
Hitachi Tokyo, Japan				Sector Scanner	
Kontron (Roche) Zurich, Switzerland		Aviscan SA		RT-400 (phased array) Abdoscan 5	Bought Grumman systems, marketed by Roche Medical Electronics in U.S. by Kuraray in Japan
Kretztechnik, GmbH Zipf, Austria	Combison 200		Combison 100		Marketed in U.S. by KT Medical
Matsushita Electric Co Tokyo, Japan		Sonovista		Device to be introduced in 1979	Sonovista is sold as Imager I by Searle Ultrasound
Nuclear Enterprises, Ltd. (EMI Technology) Edinburgh, Scotland Northbrook, Illinois	Emisonic 4200 and 4201		Emisonic 4290	Emisonic 4500	Marketed by EMI Medical in U.S.
Organon Teknika Markam, Belgium Aurora, Colorado	Echoviser	Miniviser (portable) Echobioviser		Echo-cardioviser 03	Marketed in U.S. by Metrix Teknika, Inc.
Sanei Instruments (Nippon Electric Co.) Tokyo, Japan				Device to be introduced in 1979	
Siemens Medical Systems Erlangen, Germany	Tomoscan	Vidoson 655M Multison 400			Fukuda to market in Japan
Sonicaid, Ltd. West Sussex, UK Fredericksburg, Virginia	5000 Multi-planar Scanning System	5200 Real-time Scanner			Multi-planar system produces image in specified plane
Sonometric Systems Inc. (Rorer) New York, New York	Ophthalmic Scanner				
Toshiba Medical Systems Tokyo, Japan Carson, California	SAC-10A	SAL 10A (phased array)		SSH-1 A	Distributed in Europe by Oldelft

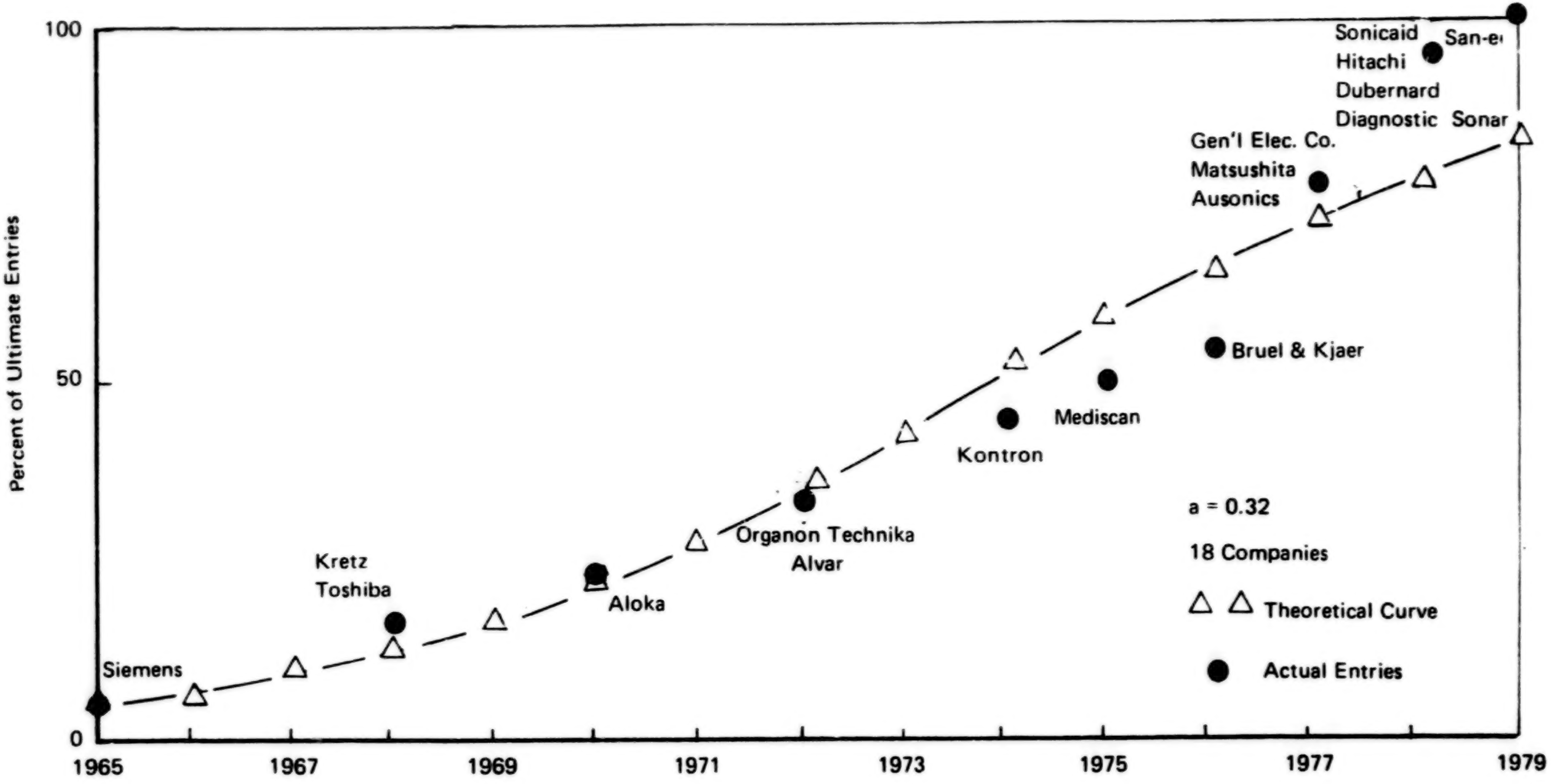


FIGURE 8 GROWTH OF COMMERCIAL ACTIVITY WITH ULTRASONIC IMAGING DEVICES OUTSIDE THE UNITED STATES

196

BEST DOCUMENT AVAILABLE

BEST DOCUMENT AVAILABLE

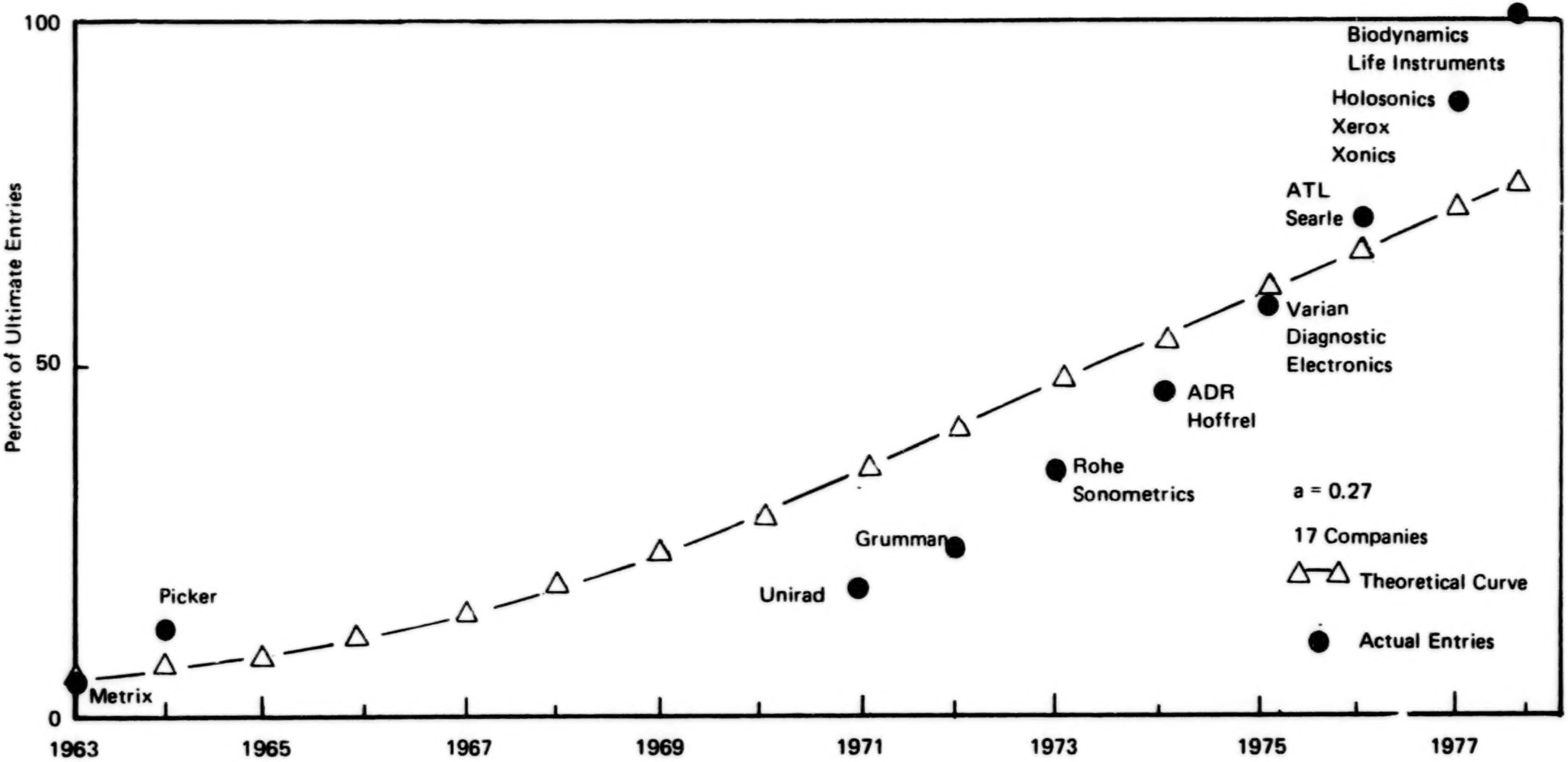


FIGURE 9 GROWTH OF COMMERCIAL ACTIVITY WITH ULTRASONIC IMAGING DEVICES IN THE UNITED STATES

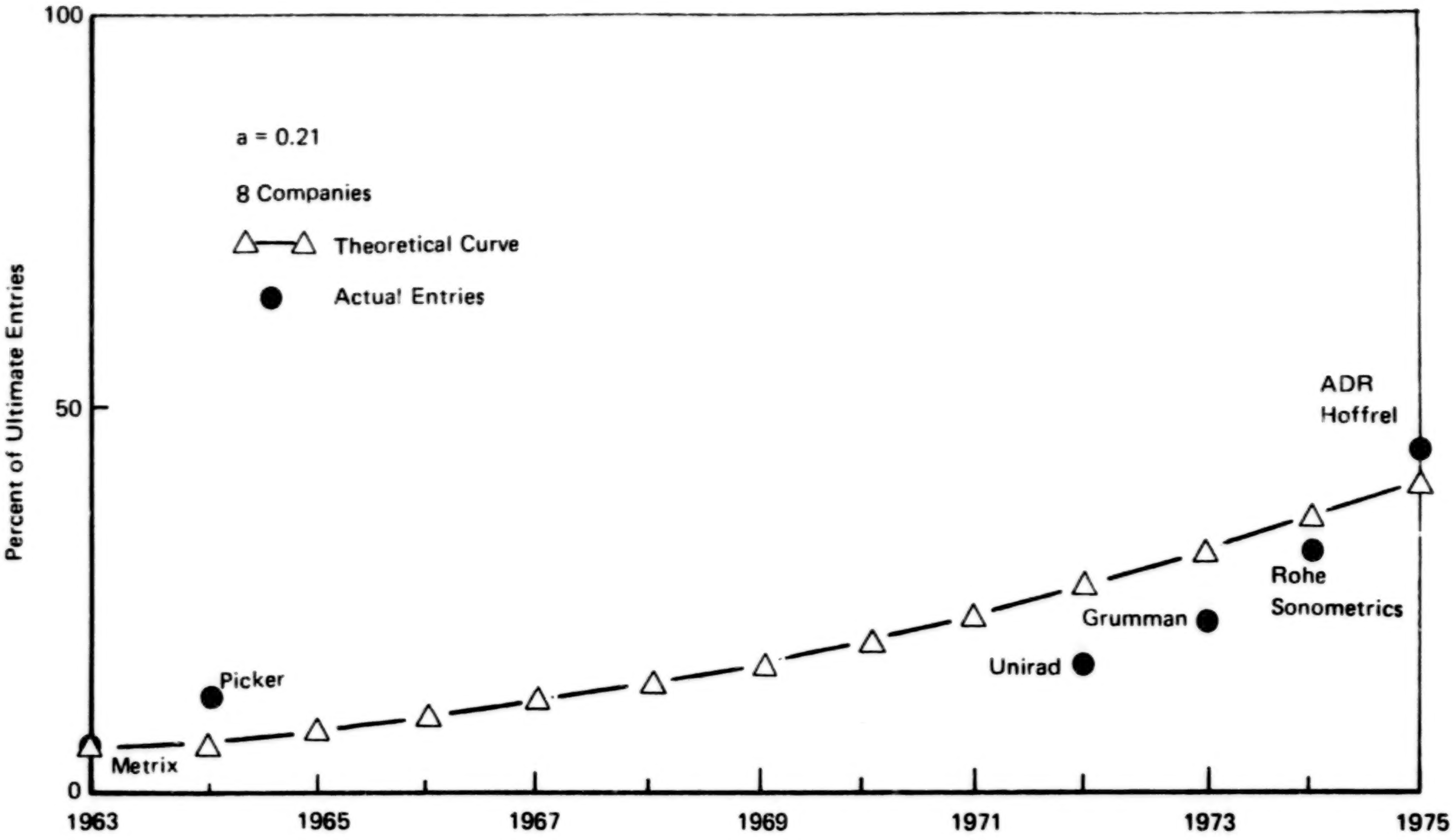


FIGURE 10 GROWTH OF COMMERCIAL ACTIVITY WITH ULTRASONIC IMAGING DEVICES IN THE UNITED STATES BEFORE NSF EXPERIMENT

198

BEST DOCUMENT AVAILABLE

BEST DOCUMENT AVAILABLE

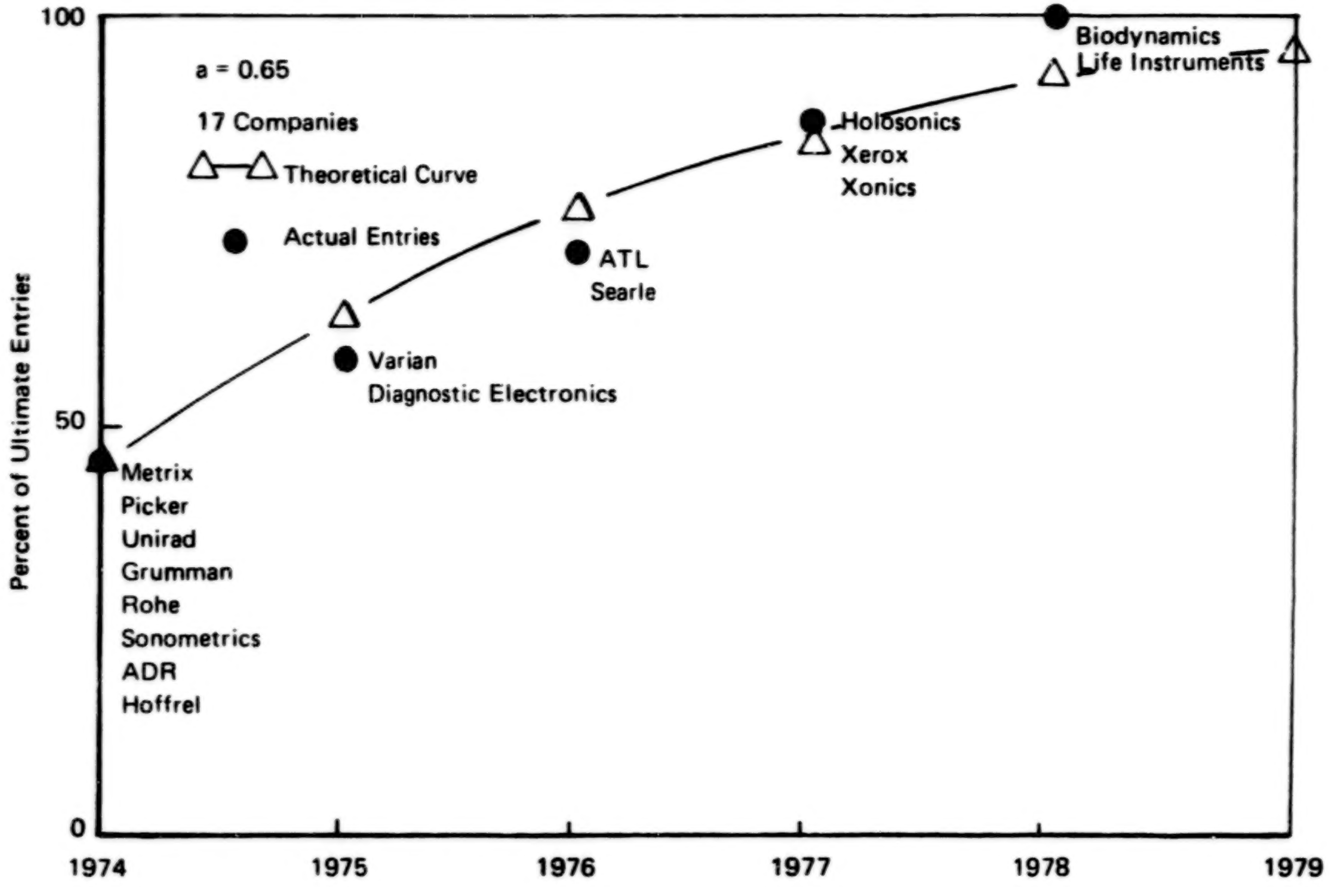


FIGURE 11 GROWTH OF COMMERCIAL ACTIVITY WITH ULTRASONIC IMAGING DEVICES IN THE UNITED STATES AFTER NSF EXPERIMENT WAS INITIATED

growth rate for U.S. companies was 0.21 before the Experiment and 0.65 after, indicating considerably more rapid growth after the Experiment was initiated. Of course, similarly rapid growth took place abroad, a development which, if our thesis, that NSF activities acted chiefly to strengthen the hands of proponents, is sound, could also be attributed in part to NSF.

E. COMPARISON AND DISCUSSION

Collecting the results from the prior sections, the values for the growth rate a were as follows:

- CT scanners a = 0.75
- nuclear scintillation cameras a = 0.26
- thermographs a = 0.81
- automated blood chemistry analyzers a = 0.28
- centrifugal blood chemistry analyzers a = 0.86
- echocardiographic instruments a = 0.26
- ultrasonic imagers outside the U.S. a = 0.32
- ultrasonic imagers in the U.S. a = 0.27
- ultrasonic imagers in the U.S. before Experiment a = 0.21
- ultrasonic imagers in the U.S. after Experiment a = 0.65

Reviewing these numbers, there are four instances of relatively high growth rates: CT scanners, thermographs, centrifugal blood chemistry analyzers, and ultrasonic imagers in the United States after the Experiment was initiated. One can find special reasons for rapid growth of participation with these instruments, as discussed below. Equally striking is the relatively long time required for significant development of participation with new medical instruments. The other histories recounted span a period of about 14 years during which competition grew gradually, and, if one included antecedents to the first commercial development, the total period of development from conception and initial experimentation through the embryonic and growth phases to full commercial development typically spans two decades.

To many people, including the National Academy of Engineering and the National Science Foundation at the time the Experiment was initiated, such a long period seemed excessive. Naturally, there can be many reasons for the observed slowness, but an important one is a basic difference between medical and other kinds of technology, namely, a step between technical and commercial development, that is, clinical development. Clinical development is more complicated and drawn out than clinical trials. It is the exploration of applications of new technology, usually simultaneously depending on and contributing to medical knowledge.

Medicine is often spoken of as an art, which is a reflection of our incomplete understanding of physiology and pathology, the limited diagnostic data accessible to a physician about the internal state and workings of his patient, the limitations of possible therapeutic interventions, and the uncertain relationships among pathology, diagnosis and therapy. There is still a great deal to learn about physiology and pathology, but even within the scope of what is known, the correspondence between disease states and measurable or observable characteristics of a patient may be uncertain. In diagnosis a physician is frequently obliged to work with murky data because getting data can be expensive, dangerous, or impossible. The outcome of therapy, when a therapy is known, is frequently uncertain.

To elaborate on this point with regard to diagnostic imaging devices, from which most of our examples were drawn, the images produced by X-ray machines, CT scanners, gamma cameras, thermographs, or ultrasound devices do not make an image like that we would see if we cut into a patient. In many diagnostic applications the resemblance between the image and the anatomy is useful only for orientation and localization, while some other feature depending on the interaction between the probe (X-rays, gamma rays, ultrasound, etc.) and tissue is the essential diagnostic clue. Learning about these clues is time-consuming because it usually requires trying something on a series of patients, confirming or refuting the result by another established and reliable means, and modifying the technology and the technique until useful applications are found or the device is discarded. Furthermore this learning must be done in circumstances where simple scientific experiments, changing one variable at a time, are seldom possible. Most new technologies carry known or conceivable dangers, and ethical constraints abound. This gradual expansion of accepted clinical applications of new technology, often depending on iterative improvements in technology and technique, is what takes so long.

Clinical trials are possible only after applications of a new technology have been developed sufficiently to consider the technique competitive with some other. Although it sometimes seems as if a new medical technology bursts upon the scene and clamors for trials, the histories indicate that technical and clinical development almost always has been going on for some years before trials could be considered. With this thought in mind, one can see that the idea of the VA or anyone else conducting clinical trials while clinical applications of ultrasound were still being explored was not received enthusiastically by manufacturers who had a lot at risk. In the circumstances it is little wonder that the VA never did produce plans for clinical trials; too much remained to be explored.

We note that, quite aside from the Experiment, NSF has supported and continues to support research on tissue signatures of ultrasound — that is, relationships between characteristic ultrasonic patterns and specific pathological conditions. Forging this link between what this new technology can show and what a diagnostician needs to know is essential to expanding clinical applications, on which depends commercial development. Thus, this activity by NSF, though not part of the Experiment, has contributed to commercial development of ultrasound.

There are other factors which affect the speed with which commercial developments take place, and many of them were outside the scope of the Experiment. Among the rapidly developed instruments, thermographs, with a = 0.81, developed quickly because the technology of infrared imaging had been developed by a number of companies for military and scientific purposes, and when a medical application had been perceived, it was comparatively easy to produce machines for this purpose. Centrifugal blood chemistry analyzers, with a = 0.86, were developed quickly because the technology was licensed by the government more or less simultaneously to several competitors. In these respects both of these instruments do not fit the pattern of medical device development described above.

Putting these two instruments aside, CT scanners, with a = 0.75, did develop with almost unheard-of rapidity. In this case there was an unusual conjunction of favorable factors — a brilliant technological conception and achievement in Hounsfield's original design; a new and rich field for technical development, a clear-cut breakthrough in clinical applications producing easily interpreted and obviously superior images, and the promise of substantial commercial rewards. Thus commercial growth of CT scanners was breathtaking and widely commented upon. (As it happens, this rapid development contained the seeds of its own destruction, and CT scanners today are held up as egregious examples of runaway medical costs. They became the focus of cost-containment efforts with the result that only half of the 14 companies who originally entered the field are still in it; only two or three are making money selling CT scanners, and perhaps none will ever recover their development costs.)

The growth of commercial development of ultrasound imaging devices after the Experiment was initiated, with a = 0.65, compared to a = 0.21 before, is an indication that the Experiment did affect their development. As we have said, this effect seems attributable not to the specific activities of the Experiment, none of which worked out as anticipated, but simply to the existence of the Experiment and the role this played in strengthening the hands of proponents and calling to everyone's attention the existence and scope of competition.

It must be acknowledged, however, that this outcome probably would not have been observed if certain other conditions regarding ultrasound had not been so. Ultrasonic imagers were already under development in at least a dozen U.S. firms when the Experiment was initiated and their work on beamforming, automatic scanning, gray scale, and scan conversion was bearing fruit. Ultrasound was believed to be harmless, and little evidence to modify this belief has emerged. Clinical applications in cardiology, obstetrics, and oncology had already been established, and the technical improvements served to enhance performance and extend applications. The cost of ultrasound devices was low enough not to draw the attention of regulators. Thus, development of ultrasonic imagers was already proceeding in the United States and the Experiment accelerated it, and subsequent development did not encounter obstacles which might have vitiated the effect of the Experiment.

It was asserted at the time the Experiment was conceived that ultrasonic imagers were being developed abroad at a pace considerably greater than that in the United States. This is borne out to a degree by the figures, which show an over-all rate abroad of a = 0.32 while that in the United States was a = 0.27 (combining the periods before and after the Experiment was initiated). From what can be observed about commercial development, there are mild reasons for this assertion. However, the fact that there are now 18 foreign companies producing ultrasonic imagers and 17 domestic companies suggests that the difference is not great. Also since the number of foreign companies has kept pace with those in the United States, a similar surge must have taken place abroad after the Experiment was initiated. This must be attributed in part to the various external factors enumerated above, favoring development of medical ultrasound, but it seems plausible to believe that the Experiment also affected foreign development in the same way as it did U.S. development. The world of medical technology is international, as a review of the histories makes clear.

203

III. CONCLUSIONS

There are three kinds of conclusions to draw from the histories recounted earlier in this report:

- conclusions about the effectiveness of the Experiment itself and whether the mechanisms of writing specifications, arranging trials, initiating training, and supporting research have had an effect on the development of ultrasonic imaging;
- conclusions about the development of medical instrumentation in general and whether the mechanisms used in the Experiment could be usefully applied in other situations; and
- conclusions about the government's role in development of medical technology and whether it is desirable to initiate actions to stimulate such developments.

These three matters are addressed in the following three sections.

A. CONCLUSIONS ABOUT THE EXPERIMENT

In the role which NSF defined for itself in 1973 it seems fair to say that their activities did stimulate development and usage of ultrasonic imaging devices. This conclusion is borne out by comparison of this development with others, as described in Section II, and by the perception of most persons involved in development of this instrumentation at the time the Experiment was carried out. At the same time it must be admitted that the Experiment did not succeed by the mechanisms originally anticipated.

There were, it seems to us, two major fallacies in undertaking to write specifications. It was done in response to observations made by the National Academy of Engineering, which had concluded that industry was "not sufficiently involved in the formulation of biomedical engineering needs and potential solutions; [was] unaware of priorities in the needs for development, and there [was] inadequate feedback of medical and technical problems and capabilities that evolve from medical needs, advancing technology, and industrial resources." The specifications were intended to bridge the gap between needs and solutions and to present industry with a well-considered opportunity to make money by fulfilling a real need with an advanced but technically feasible instrument.

Given the number of companies active in various aspects of biomedical instrumentation, as indicated in the histories, one wonders if the

204

NAE's premise was sound and industry was really having trouble formulating needs and identifying solutions. One must acknowledge that free market forces provide a powerful stimulus for businessmen and engineers to seek out needs and solutions and to put them together. A number of companies were doing just that, both here and abroad, in ultrasound before the Experiment was initiated. For a variety of reasons mentioned earlier in this report, most individuals active in ultrasonic imaging were not impressed by the NSF specifications. They saw requirements not well connected to medical needs and limitations not well connected to potential technological solutions. The fact that no instrument meeting the specifications exists today, is a powerful argument for this inadequacy.

Thus, the first fallacy lay in the presumption that NSF could find someone to write specifications recognizably superior to what industry was already doing. This is not to impugn the skill or sense of those who did write the specifications. It is only to cast doubt on whether there was any reason to think they could do a better job than the people already pursuing the same matter.

The second fallacy was mentioned earlier — that in the normal course of commercial affairs each company seeks to distinguish itself on the basis of efficacy, quality, features, price, or some other attributes. Thus, the last thing a company wants is an instrument exactly like someone else's, and with this insight it is clear that the specifications were doomed to rejection from the beginning.

As noted in Section I, the offer to undertake clinical trials appeared to most participants to be of little benefit and considerable risk. Contrary to the findings of the National Academy of Engineering most companies, once they have made a commitment to bioengineering, have little difficulty finding collaborators in the medical community. After all, a new instrument provides an academic physician a chance to help his patients and to contribute to the development of his profession, as well as certain rewards in publishing, consulting fees, and grants. In any case, most participants said that the NSF's offer to conduct clinical trials addressed a nonproblem.

There was also some misunderstanding of the nature of the trials. There is a need from time to time in medicine to conduct formal clinical trials in which one instrument is compared with another under an explicit, carefully designed protocol. Such trials are only possible when usage of both instruments has become well-established, their capabilities and limitations are well-known, and the persons using them are skilled in their operation. None of these conditions applied to ultrasonic imaging during the course of the Experiment. Instead physicians and technicians

205

were still exploring applications and developing their skills. It was the intention that VA physicians from several specialties would become proficient in the use of these devices in various applications and thus become able to conduct trials, but this possibility appeared too remote and too risky to most participants. The VA had no prior qualifications and participants were skeptical of the VA's ability to perform.

The third NSF action — contributing to training programs — was a by-product of the VA's activities in getting ready to conduct clinical trials. Recognizing that skills would have to be developed before trials, the VA had plans to train many physicians. This was something of a bone of contention with NSF, since the plans threatened to use up much of the $3 million earmarked for the Experiment, and ultimately only one school received any money for training. On the other hand, it is true that training practitioners may pace development of new medical instrumentation, and companies in the field viewed training activities with approval.

Finally, apart from the Experiment NSF supported research on tissue signatures and promoted interchange of data. Nearly everyone could agree that these scientific activities, pushing forward the frontiers of knowledge, were generally desirable and a reasonable employment of government funds.

Thus, we are left with very little in the way of direct effects of NSF activities. Two actions — writing specifications and offering to conduct clinical trials — were rejected by the participants; one action — training — never amounted to much in the Experiment; and another action — supporting research — went on outside the Experiment. In spite of these observations it still seems to participants and observers that NSF's activities did stimulate the field, not particularly through any specific activity but generally by calling attention to the potentialities of ultrasound for meeting medical needs in a new and safe manner. None of the Survey Team's findings was news to anyone already in the field, but persons who had entertained doubts found them much diminished by the public position of a prestigious government agency that medical ultrasound had a bright future. Thus, the simple existence of an Experiment addressed to stimulation of ultrasonic imaging devices did much more than any specific action in the Experiment. It was clear that ultrasonic imaging would develop with or without NSF participation, but the Experiment accelerated development by strengthening proponents and making obvious the scope of competition.

B. CONCLUSIONS ABOUT DEVELOPMENT OF MEDICAL INSTRUMENTATION

The goal of the Medical Instrumentation Experiment was not improved ultrasonic imaging devices but improved methods for government stimulation of what was believed at the time to be a desirable end, namely, more rapid transfer of technology to medicine. Having concluded that the NSF's activities in the Experiment contributed to that end, though not by the mechanisms originally envisioned, the question arises whether NSF, or any other government agency, could apply the lessons learned to stimulation of other technologies in medicine.

It can be noted at the outset that this kind of governmental activity — stimulating development in certain directions without actually spending government money on the development itself, leaving in place all the motivations and operations of the free enterprise system —has no clearcut precedents and that NSF was feeling its way in an area where there were many constraints and considerable opposition. Constraints included existing procurement practices, handling of proprietary information, and legitimate retention of patents. Opposition was strongest from those in government who saw a new role — and therefore new responsibilities and new expenses — for government. There was no question it was a new role and, if it were to be codified, it would entail new responsibilities and expenses.

Whether the government could effectively play this role year in and year out seems to us very doubtful. Their ambition would be to identify new and desirable technologies and to take actions which would stimulate applications in medicine. As we have seen, ultrasonic imaging was already developing and had considerable momentum when the Experiment started. The Experiment accelerated development but did not fundamentally alter the situation. The success achieved by ultrasonic imaging is more a reflection of the intrinsic merits of the technique — easily recognized images, low cost, harmlessness, and the promise of new diagnostic realms open to a new interrogating source — than of any action taken by NSF. (Were the Experiment beginning today, one supposes that nuclear magnetic resonance [NMR] might be chosen as the subject, but its ultimate success in medicine is much more in doubt.)

In the free enterprise system thousands of intelligent and informed persons — inventors, entrepreneurs, industrialists, venture capitalists, investors, and their agents — are continually trying to find technologies which will be successful. It is true that there are dozens of mistakes for every correct identification, but the effort goes on because there are rewards for finding the right answers. Given this situation, it is hard to see why a government agency should be more astute.

207

The government's role seems better conceived when it addresses itself to stimulating developments which would probably not occur in the normal operation of the free enterprise system. From this point of view the Experiment with ultrasonic imaging did not address itself to the right problem, since everything which did happen probably would have happened anyway. The Optacon tactile display reader, on the other hand, probably would not have been designed if government funding had been unavailable because the ultimate market, considering limitations of the device itself and the resources available to the blind, was too small. Support of some scientific work, such as development of tissue signatures, can stimulate the field and accomplish a job which companies would be unlikely to address in depth. Support of training also stimulates a field and addresses a need which companies cannot easily undertake.

Thus, it seems to us that beyond the traditional roles in supporting scientific research and education, the government would have great difficulty trying to replicate the stimulants which worked in the Medical Instrumentation Experiment. Spotting the winners before they have won is too hard to consider doing repeatedly. After one or two failures the credibility and prestige on which the success of the Experiment rested would be spent.

C. CONCLUSIONS ABOUT THE GOVERNMENT'S ROLE

Finally, there are questions about whether it is even desirable to stimulate the transfer of technology to medicine. There are many today who argue that the government's role is to put brakes on the headlong proliferation of technology in medicine, a profound change from the view which underlay the Medical Instrumentation Experiment.

This attitude stems from a number of causes but the principal one is a recognition of the costs entailed by new technology. Objectively speaking, it is hard to believe that better diagnostic or therapeutic devices, which have successfully run the gantlet of technological and clinical development, really increase a global cost/benefit ratio. It is true that new technology introduces palpable new costs but because of it more people survive and live better, and these are the compensating benefits. However, this point is hard to make convincing and many today would dispute it.

In any case, a great deal of government effort today is spent through Health Systems Agencies and Offices of Technology Assessment to hold back the proliferation of technology in medicine, and it seems questionable that the right hand should stimulate developments while the left hand holds them back.